SEED INVIGOURATION FOR YIELD ENHANCEMENT IN GRAIN COWPEA (*Vigna unguiculata* L. Walp)

by

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"SEED INVIGOURATION FOR YIELD ENHANCEMENT IN GRAIN COWPEA (*Vigna unguiculata* L. Walp)"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Place : Vellayani
Date : 20/7/2019

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CERTIFICATE

Certified that this thesis entitled **"SEED INVIGOURATION FOR YIELD ENHANCEMENT IN GRAIN COWPEA (*Vigna unguiculata* L. Walp)"** is a record of research work done independently by Ms. ANJU. B. RAJ 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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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

ANOVA	:	Analysis of variance
B	:	Boron
B: C	:	Benefit cost
$CaNO_3$	:	Calcium nitrate
CD (0.05)	:	Critical difference at 5 % level
CMC	:	Carboxy methyl cellulase
CGR	:	Crop growth rate
CRG	:	Coefficient of rate of germination
$CuSO_4$	:	Copper sulphate
DAP	:	Diammonium phosphate
DAS	:	Days after sowing
DMP	:	Dry matter production
$dS\ m^{-1}$	:	deci Siemens per metre
day^{-1}	:	Per day
EC	:	Electrical conductivity
EDTA	:	Ethylenediaminetetraacetic acid
et al.	:	Co-workers/ Co-authors
$FeSO_4$	:	Ferrous sulphate
FYM	:	Farm yard manure
Fig.	:	Figure
g	:	Gram
g^{-1}	:	Per gram
GI	:	Germination index
GP	:	Germination percentage
GRI	:	Germination rate index
h	:	Hour

ha	:	Hectare
ha^{-1}	:	Per hectare
HCl	:	Hydrochloric acid
H_3BO_3	:	Boric acid
ISTA	:	International seed testing association
K	:	Potassium
KAU	:	Kerala Agricultural University
KCl	:	Potassium chloride
KH_2PO_4	:	Potassium dihydrogen phosphate
kg	:	Kilogram
kg^{-1}	:	Per kilogram
KNO_3	:	Potassium nitrate
L	:	Litre
LAI	:	Leaf area index
M	:	Molar
m^2	:	Square metre
MDG	:	Mean daily germination
mg	:	Milligram
MGT	:	Mean germination time
$MgNO_3$	:	Magnesium nitrate
mm	:	Millimetre
mL	:	Millilitre
N	:	Nitrogen
$Na_2S_2O_3$	:	Sodium thiosulphate
NS	:	Not significant
No.	:	Number
P	:	Phosphorus
pH	:	Potenz hydrogen
RBD	:	Randomized block design
RGR	:	Relative growth rate

S	:	Sulphur
SG	:	Speed of germination
SVI I	:	Seedling vigour index I
SVI II	:	Seedling vigour index II
SEm	:	Standard error of mean
T_{50}	:	Time to 50 per cent germination
viz.,	:	Namely
Zn	:	Zinc
ZnO	:	Zinc oxide
$Zn_3(PO_4)_2$	:	Zinc phosphate
Zn-Lys	:	Zinc lysine
$ZnSO_4$	:	Zinc sulphate

LIST OF SYMBOLS

%	:	Per cent
@	:	at the rate of
°C	:	Degree Celsius
µ	:	Micro
₹	:	Rupee

15

Introduction

1. INTRODUCTION

Pulses are quick growing leguminous food crop after cereals, being the affordable and fastest means to enhance the protein production in developing countries. About 15 per cent of the dietary protein is met from pulses in India as against nine per cent in the world. According to World Health Organization, the dietary requirement of pulses per day per person is 80 g (ASSOCHAM, 2012).

Pulse production in Kerala is not sufficient to meet the dietary requirement of our people. The major constraint in pulse production is the low productivity that emphasis the necessity for the adoption of improved management techniques.

Cowpea (*Vigna unguiculata* (L.) Walp is the most widely cultivated pulse crop of Kerala. It is an important multipurpose grain legume crop which performs well as pure and as intercrop. Although cowpea is grown throughout the year, over a variety of farming situations, a large gap exists between the supply and demand for grain cowpea within the state. Thus, there is an urgent need to boost the production and productivity of grain cowpea.

There are certain challenges which reduce the yield and productivity of grain cowpea. The major challenges noticed are flower shedding, poor pod and seed setting and shrivelling of grains. These problems may be ascribed to the deficiencies of major and minor nutrients or due to biotic and abiotic stresses. Deficiencies of micronutrients especially zinc (Zn) and boron (B) are widely noticed in pulses. Zinc plays a vital role in plant metabolism and is known to be involved in nodule formation and improved N fixation (Shukla and Yadav, 1982). Boron is imperative for cell division, elongation and cell wall development in plants. It is also needed for the maintenance of nodule cell wall, membrane structure and development of symbiosome (Bolanos *et al.*, 2001). Since B plays a significant role in the development of reproductive organs, compared to field crops, legume crops require large amount of B. Its deficiency caused flower drop and reduced fruit set due to the malformation of reproductive tissues and its effect on pollen germination. Boron deficiency also restricts the plant response to nitrogen (N) because N intensifies the demand for boron. Hence, application of Zn and B can enhance the

17

yield by reducing the flower drop and enhance the pod and seed setting in grain cowpea.

Soil and foliar application are the most common means of micronutrient application to crops. But there are some limitations in the adoption of these two methods. With respect to soil application, since the quantity of micronutrient applied is very less, it is difficult to spread uniformly over the soil. Though the foliar application is effective in correcting the micronutrient deficiencies, it is too laborious. Seed priming and pelleting with micronutrients are the two simple inexpensive strategies for overcoming these problems. There are several advantages to this approach: the effect of uneven application of micronutrients to the soil can be avoided, initial uptake and the nutrient availability in the early life cycle of the plant is guaranteed and the amount required is very less. Moreover, it is cost effective than soil and foliar application.

Inconsistent rainfall, degraded soils, inferior quality seed and changing climatic scenario contribute to a condition where better crop establishment and yield are often the exemption rather than the rule. These unfortunate events ultimately lead to crop failure, which makes crop production expensive. Seed pelleting and priming are the two cost effective seed invigouration methods that can be safely employed for pulse crops to enhance the germination, seedling establishment and seed yield. Seed invigoration is relatively a novel term and has been interchangeably used for both seed priming and seed pelleting (Farooq *et al.,* 2009). Seed invigouration with micronutrients ensures better stand establishment, increased seedling vigour, disease and stress tolerance and increased yield.

With this back ground, the present study entitled ''Seed invigouration for yield enhancement in grain cowpea (*Vigna unguiculata* L.Walp)'' was carried out with the following objectives.

- To assess the effect of seed invigouration with zinc sulphate and borax on grain cowpea.
- To evaluate its effect along with *Trichoderma viride* on growth and yield of the crop.

Review of Literature

2. REVIEW OF LITERATURE

Cowpea (*Vigna unguiculata* (L.) Walp is an important multipurpose pulse crop which performs well as pure and inter crop in coconut garden. In Kerala it is mostly cultivated under rainfed condition in rice fallows and marginal lands. Deficiencies of micronutrients especially Zn and B have been widely reported in pulses. Seed priming and pelleting with micronutrients are the two simple inexpensive strategies for micronutrient application.

Many investigators have explained the mechanism of better stand establishment, increased seedling vigour, disease and stress tolerance and increased yield due to seed invigouration techniques. The current state of knowledge regarding the effect of Zn and B on plant growth, nodulation, physiological parameters, yield and quality, effect of seed invigouration in crop production, its effect on germination and seedling vigour, growth and yield parameters and yield of crop plants and the effect of *Trichoderma* seed treatment in pulses are reviewed in this chapter.

2.1 EFFECT OF ZINC ON PLANT GROWTH

Zinc plays a major role in plant growth and development. Stevenson and Cole (1999) reported that a healthy plant contain 27 to150 mg Zn kg^{-1} plant biomass. Deficiency of Zn causes chlorosis, sterility, reduction in leaf size and reduction in spikelet number (Cakmak, 2000). Zinc also have a significant role in plant metabolism and synthesis of auxins, carbohydrate, phosphate and nucleic acid (Latef *et al*., 2017).

Zinc is an important constituent of enzymes and proteins. It is the only metal element present in all the six enzyme classes, oxidoreductases, transferases, hydrolases, lyases, isomerases and ligases (Auld, 2001). It also acts as the co-factor of enzymes and stabilizes the structure of proteins (Evans and Halliwell, 2001). It also plays a vital role in stomatal regulation and maintaining an ionic balance in plant system (Baybordi, 2006). Zinc is also involved in chlorophyll production, pollen function, fertilization and germination (Pandey *et al*. 2006; Cakmak, 2008).

20

Zinc content in newly developed radicles and coleoptiles were much higher up to 200 mg kg^{-1} (Ozturk *et al.*, 2006). The high concentration of Zn indicates the role of Zn in physiological processes *viz.*, protein synthesis, cell elongation, membrane function and resistance to abiotic stresses in early seedling development.

Marschner (1995) reported that higher seed Zn content during germination and seedling development stage expressed greater resistance to soil-borne pathogens, thus ensured good crop stand and better yield.

2.2 EFFECT OF BORON ON PLANT GROWTH

Boron is considered to be an essential micronutrient element for plant growth and development. Boron deficiency leads to several physiological damages in plant. It is considered to be essential for sugar transport, synthesis of cell wall, cell wall structure, metabolism of carbohydrate, RNA, phenol and indole acetic acid, respiration and membrane integrity (Parr and Loughman, 1983).

Boron is essential for maintaining the structural integrity of plasma membrane. Boron enhanced the uptake of K^+ ion and membrane bound ATPase activity which caused the hyperpolarization of plasma membrane. Serrano (1989) observed that the driving force for K^+ influx was increased by the pumping activity of membrane and hyperpolarization. Schon *et al.* (1990) observed an enhancement in the opening and closing of stomata by increased K^+ ion influx due to boron in dayflower (*Commelina communis*). Cheng and Rerkasem (1993) opined that plasma membranes are highly leaky and lost their structure due to B deficiency.

Boron is involved in the functioning of plant reproductive tissues. Marschner (1995) reported that B is found to be essential for pollen tube germination, cell elongation, cell division, male flower sterility and fruit and seed formation in plants. Aslam *et al.* (2002) reported that B nutrition leads to better pollination, seed setting and lower spikelet sterility, which finally contributed to higher grain yield in rice cultivars. Tariq and Mott (2007) pointed out that B deficiency during flowering prevents the pollen tube growth which causes pollen sterility, flower drop and poor pod setting. Boron deficiency was more under dry weather and low moisture conditions and its deficiency reduced the number of pollen grains, pollen germination and filling up of grains. It was also observed that foliar nutrition of B enhanced the flower development, pollen grain formation, pollen viability, pollen tube growth and seed development in green gram (Praveena *et al.*, 2018).

Rerkasem (1996) reported that the growing points *viz.*, root tips, new leaves and buds required higher amount of B than mature tissues. Dell and Huang (1997) pointed out that B deficiency in soil retards root elongation, cell division in the root tip, leaf expansion and reduction in photosynthesis. Boron is also involved in root growth (Moeinian *et al.*, 2011) and impart stress tolerance in plant and enhances grain production (Hussain *et al.*, 2012).

2.3 EFFECT OF ZINC AND BORON ON NODULATION IN PULSES

Boron had significant effect on symbiotic N fixation. Bolanos *et al.* (1994) reported that absence of B in the culture medium resulted in reduction in the number of nodules and variations in nodule development.

Boron is essential for the cell wall maintenance of nodule and symbiosome development (Bolanos *et al.*, 2001). Subasinghe *et al.* (2003) observed that B had a positive effect on nodulation and observed that up to 4 ppm, B enhanced the dry matter content and nodulation, but beyond 4 ppm it had negative impact. Noor and Hossain (2007) also revealed that B is essential for nodulation and N fixation in legumes. Application of B 0.5 kg ha^{-1} significantly enhanced the N fixation in cowpea and ground nut by 89 per cent and 126 per cent, respectively over control, however higher dose (1 kg ha^{-1}) significantly reduced the N fixation in cowpea and groundnut (Yakubu *et al.*, 2010). Parry *et al.* (2016) reported that application of 30 kg S + 2 kg B ha^{-1} recorded higher number of nodules per plant, nodule fresh and dry weight in garden pea. In black gram, the highest number of nodules per plant and nodule dry weight was observed in the treatment receiving 0.2 per cent borax along with 0.1 per cent Zn EDTA, 2 per cent urea and 2 per cent single super phosphate (Meena *et al.*, 2017). Quddus *et al.* (2018) observed that nodulation increased with increase in rate of B application and the highest number of nodules was observed, when B was applied @ 2 kg ha^{-1}.

Zinc plays a major role in N fixation through nodule formation (Nandwall *et al.*,1990; Balusamy *et al.*,1996). Khorgamy and Farina (2009) reported that in chick pea, application of $ZnSO_4$ 20 kg ha^{-1} markedly increased the root nodulation. Das *et al.* (2012) observed that, Zn plays a major role in leg haemoglobin synthesis and also observed that nodule number, size, leghaemoglobin content and dry weight of nodules depend on the Zn availability. Application of Zn 5 kg ha^{-1} resulted in 91 per cent enhancement in nodulation in soybean (Chauhan *et al.*, 2013). Soil application of 15 kg Zn ha^{-1} recorded higher number of nodules, effective nodules and nodule fresh weight per plant in cowpea (Upadhyay and Singh, 2016). However, Debnath *et al.* (2018) observed that, soil application of Zn 7.5 kg ha^{-1} along with recommended dose of fertilizers recorded greater number of nodules per plant in cowpea. In cluster bean, nodule number and nodule fresh weight were greatly influenced by soil application of Zn 5 kg ha^{-1} (Kuniya *et al.*, 2018).

2.4 EFFECT OF ZINC AND BORON ON PHYSIOLOGICAL PARAMETERS IN PULSES

Tripathy *et al.* (1999) reported that soil application of zinc 25 kg ha^{-1} + B 10 kg ha^{-1} recorded significantly higher leaf area index (LAI) in soybean. In mung bean foliar application of one per cent Zn recorded significantly higher LAI (Mondal *et al.*, 2011). Thamke (2017) pointed out that Zn nutrition significantly influenced the LAI of pigeon pea and higher LAI was recorded at 15 kg $ZnSO_4$. Seed polymer coating with $ZnSO_4$ + B + $FeSO_4$+ ammonium molybdate each at 2 g kg^{-1} seed followed by foliar application of $ZnSO_4$ + B + $FeSO_4$+ ammonium molybdate (0.5 + 0.2 + 0.5 + 0.1 per cent) at 50 DAS and 60 DAS recorded significantly higher LAI in chick pea (Shinde *et al.*, 2017).

Akay (2011) reported that application of Zn 1 kg ha^{-1} significantly enhanced the chlorophyll content in chickpea. Application of B 4 µg g^{-1} resulted in increase in chlorophyll and carotenoid content in mung bean (Seth and Aery, 2014). Rahdari *et al.* (2013) reported that in soybean, chlorophyll and carotenoid content increased with the application of Zn 200 μM. Seed polymer coating with $ZnSO_4$ + B + $FeSO_4$+ ammonium molybdate each at 2 g kg^{-1} seed along with two foliar sprays (0.5+ 0.2 + 0.5 + 0.1 per cent) recorded significantly higher chlorophyll content in chick pea (Shinde *et al.*, 2017). Samreen *et al.* (2017) reported that in mung bean, the highest chlorophyll content was observed at 0.2 μ M concentration of Zn. Foliar nutrition of potassium nitrate 2 per cent + boric acid 50 ppm +$ZnSO_4$ 1 per cent at 30 days after sowing (DAS) and 60 DAS significantly enhanced the total chlorophyll content in soybean (Gowthami *et al.*, 2018). In pigeon pea, foliar application of 0.5 per cent $ZnSO_4$ resulted in 3 to 8 per cent increase in chlorophyll content (Purushottam *et al.*, 2018).

Mahilane and Singh (2018) observed higher crop growth rate (CGR) with the application of Zn 7.5 kg ha^{-1}. In black gram, foliar application of $ZnSO_4$ 0.3 per cent and H_3BO_3 0.2 per cent recorded significantly higher CGR and relative growth rate (RGR) than control (Akshata, 2013).

2.5 EFFECT OF ZINC AND BORON ON YIELD OF PULSES

Zinc fertilization had positive effect on the yield of pulses. Application of Zn 5 kg ha^{-1} along with S 60 kg ha^{-1} recorded 67 per cent higher seed yield over control in mung bean (Mali *et al.*, 2003). Khorgamy and Farina (2009) opined that soil application of $ZnSO_4$ 20 kg ha^{-1} markedly enhanced the seed yield in chickpea cultivars. Foliar application of 0.4 per cent Zn at pre flowering and post pod forming stage increased the seed yield by 16.2 per cent over control in lentil (Singh and Bhati, 2013). Umesh and Shankar (2013) revealed that soil application of $ZnSO_4$ 12.5 kg ha^{-1} along with the recommended dose of NPK recorded the highest seed yield (1759 kg ha^{-1}) in pigeon pea. Malik *et al.* (2015) revealed that significantly higher seed yield per plant (78.2 g) was recorded with foliar nutrition of 20 ppm Zn. In black gram, foliar nutrition of secondary nutrients *viz.*, $CaNO_3$, $MgNO_3$ and S each at one per cent along with 0.2 per cent $ZnSO_4$ at 25 DAS and 45 DAS recorded the highest seed yield (Lakshmi *et al.*, 2017). Kuniya *et al.* (2018) indicated that soil application of Zn 5 kg ha^{-1} greatly enhanced the seed and stover yield of cluster bean.

Boron is essential for pod and seed formation in pulses (Vitosh *et al.*, 1997) Soil application of B 1 kg ha^{-1} alone or in combination with S 30 kg ha^{-1} were found best for higher yield in soybean (Sarker *et al.*, 2002). Foliar application of borax 0.2 per cent at vegetative and flowering stage significantly enhanced the seed yield in mung bean compared to control (Patra and Bhattacharya, 2009). Combined application of B 1.5 kg ha^{-1} + Zn 3 kg ha^{-1} enhanced the seed yield in lentil (Quddus *et al.*, 2014). Chatterjee and Bandyopadhyay (2017) observed that foliar nutrition of B 1.5 g L^{-1} at four weeks after planting (WAP) recorded 39 per cent higher pod yield per plant over control in vegetable cowpea. Adhikary *et al.* (2018) reported that in lentil, foliar spray of 0.5 per cent B at 15 DAS, 40 DAS and flower initiation stage recorded 26.98 per cent higher seed yield in lentil. Soil application of Zn 5 kg ha^{-1} followed by foliar spray of B 0.5 per cent at 20 DAS and 35 DAS registered the highest seed yield (2.18 t ha^{-1}) in green gram (Praveena *et al.*, 2018).

2.6 EFFECT OF ZINC AND BORON ON PROTEIN CONTENT IN PULSES

Debnath and Gosh (2011) reported that B plays a major role in metabolism of protein and nucleic acids. Foliar application of Zn 2 ppm and B 2 ppm significantly enhanced the protein content in cowpea seeds (Salih, 2013). In French bean, the highest crude protein content was observed with the application of B 1.5 kg ha^{-1} (Ganie *et al.*, 2014)).

Taliee and Sayadian (2000) opined that due to the role of Zn in N metabolism, the seed quality was improved. Pigeon pea seeds treated with $ZnSO_4$ 4 g ha^{-1} seed had significant impact on grain protein content (Sharma *et al.*, 2010). Chavan *et al.* (2012) opined that compared to soil application of Zn 20 kg ha^{-1} the higher dose of 40 kg ha^{-1} registered the highest protein content in cowpea. Application of 10 kg Zn ha^{-1} recorded the highest protein content in mung bean (Ram and Katiyar, 2013). Higher protein content was observed with soil application of Zn 5 kg ha^{-1} in cluster bean Kuniya *et al.* (2018).

2.7 EFFECT OF SEED INVIGOURATION IN CROP PRODUCTION

Farooq *et al.* (2009) opined that seed invigouration is quite a new term and be used for both seed pelleting and priming.

Scott (1989) described seed pelleting as a pre-sowing physical seed management procedure. In seed pelleting the seed-soil interface at the rhizosphere region is improved by applying growth promoting substances or substances with protective, nutritive and invigourative function on the seed surface. Seed pelleting ensures easy planting, uniformity in size, uniform stress tolerance and nourishment to the seedlings (Nargis, 1995 and Peterhalmer, 2003).

Mc Donald (2000) observed that seed priming is a pre-sowing approach for influencing the seedling development by modifying the pre-germination activity preceding the radicle emergence. Increased germination rate, uniformity in germination, faster emergence of seedlings, better allometric attributes, drought tolerance, earliness in flowering and increased yield are the beneficial effects of seed priming (Farooq *et al.*, 2007).

Seed priming (soaking the seeds in micronutrient solutions of definite concentration for a specific period) or seed coating with micronutrients are the two easy cost-effective methods of micronutrient application. It ensures better germination, seedling development, early flowering, early fruiting, resistance to soil borne pathogen and increased yield (Harris *et al*, 2005; Kaya *et al.,* 2007; Malla *et al.*, 2007 and Kumar *et al.*, 2008).

2.7.1 Effect of Seed invigouration on Germination and Vigour Index

Seed invigoration with Zn and B had significant influence on crop emergence, stand establishment and seedling vigour.

Zubal (1986) reported that seed pelleting favourably influenced the field emergence of legumes under field condition compared to other seed treatment methods. Soybean seeds pelleted with zinc sulphate 250 mg kg^{-1} seed significantly influenced the field emergence compared to seed pelleting with DAP 2 g kg^{-1} seed and borax 100 mg kg^{-1} seed (Srimathi *et al.*, 2001). Kavitha (2002) observed that, green gram seeds pelleted with 40 g DAP+ 100 mg $ZnSO_4$ +100 mg $FeSO_4$ + 250 mg ammonium molybdate kg^{-1} seed markedly influenced the field emergence compared to control. Rathod *et al.* (2005) reported that in soybean, seeds pelleted with $ZnSO_4$ (0.3 g kg^{-1} seed) + CMC (2 per cent) + filler significantly increased the field emergence. Vegetable cowpea seeds pelleted with $ZnSO_4$ 250 mg kg^{-1} seed and borax 100 mg kg^{-1} seed produced seedlings with significantly higher shoot length, root length, seedling dry weight and vigour index compared to non-pelleted seeds (Masuthi *et al.*, 2009). Shashibhaskar *et al.* (2009 revealed that, the seed treatment with $ZnSO_4$ 300 mg kg^{-1} seed recorded higher field emergence percentage (91) in tomato. Chick pea seeds coated with $ZnSO_4$ and borax each at 2 g kg^{-1} seed with a polymer 6 ml kg^{-1} seed registered significantly higher germination percentage (98) and speed of germination compared to control. Seedling root length, shoot length, seedling dry weight were also found significantly higher in seeds coated with $ZnSO_4$ and borax at 2 g kg $seed^{-1}$ compared to control (Shinde *et al.*, 2016).

Seed priming is a simple, cost effective pre-sowing treatment which ensures rapid and uniform germination with better stand establishment and crop yield in many crop plants. It has been successfully demonstrated in field crops, pulses and oil seeds (Sadeghian and Yavari, 2004; Harris *et al.*, 2007; Rehman *et al.*, 2011). The success of seed priming depends on crop species, priming media, concentration of priming solution, duration of priming *etc.*

Peanut seeds treated with 1000 ppm concentration of nanoscale ZnO had significant effect on seedling growth (Prasad *et al.*, 2012). Seed priming with 100 and 200 ppm $ZnSO_4$ and $CuSO_4$ showed significant effect on germination and seedling growth of *Brassica rapa* seeds under stressed and non-stressed conditions (Begum *et al.*, 2014). Among the various nutrient priming treatments, KCl (1.5 and 3 per cent), KH_2PO_4 (1.5 and 3 per cent), KNO_3 (2 and 2.5 per cent) $ZnSO_4$ (0.05 and 0.075 per cent), chick pea seeds primed in $ZnSO_4$ 0.075 per cent for 24 h was found more effective in enhancing the germination and seedling vigour (Yanglem

27

et al., 2016). Sharma and Parmar (2018) observed that chick pea seeds primed in $ZnSO_4$ significantly improved the field emergence and stand establishment. Priming with $ZnSO_4$ (10^{-3} M) was found effective in increasing the germination percentage and reducing the mean germination time and time to 50 per cent germination in low vigour cowpea seeds (Arun *et al.*, 2017). Mahmood *et al.* (2019) observed that under drought conditions, seed priming with $ZnSO_4$ 0.05 per cent modulate the germination parameters *viz.*, germination percentage, germination rate and vigour index of chick pea).

Nutripriming with B had significant effect on germination and seedling vigour of crop plants and it is the most cost-effective method of B application. Concentration and duration of priming are the two important factors to be considered while priming with B. Farooq *et al.* (2012) observed that rice seeds primed in 0.001 per cent and 0.01 per cent B significantly reduced the time taken to 50 per cent germination and enhanced the germination index and germination percentage. Significant improvement in radicle and plumule length were also observed, whereas, radicle and plumule growth were affected in seed primed in 0.5 per cent B solution. Germination was severely affected when seeds of sunflower, turnip, soybean, wheat, sugar beet, wheat, barley, rice and alfalfa were primed in 0.5 per cent B solution (Rehman *et al.*, 2012). However, Iqbal *et al.* (2017) observed that, wheat seeds primed in 0.01 M B solution for 12 h recorded higher germination percentage, less mean emergence time and higher seedling vigour index.

2.7.2 Effect of Seed Invigouration on Growth Parameters

Seed invigouration treatments significantly influenced the growth parameters of crop plants. Ramesh and Thirumurughan (2001) reported that seed pelleting with Zn increased the plant height in soybean. Significantly taller plants at flowering and harvest stage were observed with seeds pelleted in $ZnSO_4$ (Suman, 2002). Masuthi *et al.* (2009) pointed out that in vegetable cowpea, seed pelleting with 100 mg borax kg^{-1} seed recorded taller plants at 30 DAS and 60 DAS. However, branches per plant were highest in seed pelleting with $ZnSO_4$ 250 mg kg^{-1} seed. In French bean seed pelleting with $ZnSO_4$ 3 g +borax 3 g + captan 2.5 g

+ imidacloprid 2.5 g kg^{-1} seed recorded taller plants, a greater number of branches and leaves per plant (Devi *et al.*, 2017).

Harris *et al.* (2007) observed that maize seeds primed in $ZnSO_4$ for 16 h significantly enhanced the crop growth. Results of on-farm trials revealed that in chick pea, seed priming with 0.05 per cent $ZnSO_4$ significantly increased the total dry matter production (Harris *et al.*, 2008). Rice seeds primed in 0.001 per cent B produced more leaves than other treatments. Maize seeds primed in 2 per cent Zn solution + foliar application of Zn (2 per cent) at one month after sowing significantly improved the plant height (Mohsin *et al.*, 2014). Seed priming with $ZnSO_4$ 10^{-3} M concentration recorded significantly taller plants (80.7 cm) compared to control (73.1 cm) in cowpea (Arun *et al.*, 2017). Noman *et al.* (2017) observed that seed priming with Zn Lys (4.5 and 6 mg kg^{-1} seed) caused an increase in plant height and root length over control under in radish.

2.7.3 Effect of Seed Invigouration on Yield Parameters

Seed invigouration with micronutrients significantly influenced the yield attributes of crop plants. Days to flower initiation and 50 per cent flowering was observed to be less (37 and 40.34, days respectively) in seeds treated with $ZnSO_4$ + captan + imidacloprid in paprika chilli (Deshpande *et al.*, 2009). Vegetable cowpea seeds pelleted with borax 100 mg kg^{-1} seed recorded the highest 100 seed weight (9.43 g), seed recovery percentage (72.38), pod weight per plant (42.7 g), pod yield ha^{-1} (1863.7 kg), seed yield per plant (31.80 g) and seed yield ha^{-1} (1586.3 kg) (Masuth *et al.*, 2009). Shashibhaskar *et al.* (2009) reported that tomato seeds treated with $ZnSO_4$ 300 mg kg^{-1} seed recorded lesser days (58 and 64 days, respectively) for flower initiation and 50 per cent flowering and also recorded the highest 1000 seed weight (3.17 g).

Priming maize seeds in 2 per cent Zn solution followed by foliar application of 2 per cent Zn solution one month after sowing significantly improved the length and diameter of cob and 1000 grain weight (Mohsin *et al.*, 2014). Seeds primed in $ZnSO_4$ 4.5 g kg^{-1} seed significantly improved the yield attributes in aerobic rice (Mukherjee and Pramanik, 2017). Iqbal *et al.* (2017) reported that priming of wheat

29

seeds in 0.01 M B significantly improved 100 seed weight due to the role of B in grain setting. Chick pea seeds primed in $ZnSO_4$ 0.05 per cent significantly enhanced the yield attributes (Mahmood *et al*., 2019).

2.7.4 Effect of Seed Invigouration on Yield

Seed invigoration had significant effect on grain yield of crops. Srimathi *et al.* (2001) reported that in soybean, seeds pelleted with $ZnSO_4$ recorded higher field emergence and seed yield compared to seeds pelleted with DAP 2 g kg^{-1} seed and borax 100 mg kg^{-1} seed. In green gram, seeds pelleted with DAP (2 g kg^{-1} seed) + $ZnSO_4$ 100 mg + $FeSO_4$ 100 mg + ammonium molybdate 250 mg kg^{-1} seed markedly improved the germination and seed yield. Balamurugan *et al*. (2003) opined that in sesamum, there was a yield increment of 20.6 per cent over control by treating the seeds with gypsum ammonium molybdate + $ZnSO_4$ + $MnSO_4$ + borax (300 mg each kg^{-1} seed). Pelleting of vegetable cowpea seeds with borax 100 mg kg^{-1} seed recorded higher seed yield than that of seeds pelleted with $ZnSO_4$ 250 mg kg^{-1} seed (Masuthi *et al.* 2009). Seeds treated with $ZnSO_4$ 300 mg kg^{-1} seed recorded the highest yield ha^{-1} (564 kg) in tomato (Shashibhasker *et al.* 2009). Devi (2013) revealed that pelleting of French bean seeds with $ZnSO_4$ 3g kg^{-1} seed + borax 3g kg^{-1} seed+ captan 2.5g kg^{-1} seed + imidacloprid 2.5g kg^{-1} seed recorded 40.45 per cent enhancement in seed yield over control. Seed treatment with $ZnSO_4$ (3.6 g kg^{-1} seed) with the recommended quantity of NPK significantly improved the grain yield of maize (Shabaz *et al*., 2015).

Research reports revealed that seed priming with Zn and B had favourable effect on the grain yield of many crops. Slaton *et al*. (2001) observed that rice seeds primed in $ZnSO_4$ 4.7 g kg^{-1} seed registered 28.25 per cent yield enhancement over control. Maize seeds primed in 1 per cent $ZnSO_4$ for 16 h resulted in 27.10 per cent increase in grain yield over control (Harris *et al*., 2007). Harris *et al.* (2008) revealed that, priming of wheat seeds in 0.3 per cent Zn solution for 10 h resulted in 14 per cent yield enhancement over control. He has also reported that seed priming chick pea seeds with 0.5 per cent Zn for 10 h resulted in 19 per cent yield enhancement over control. Compared to soil and foliar application of B, seed priming is the most economical and viable option for enhancing the yield in rice (Rehman *et al.*, 2014). Maize seeds primed in 0.5 per cent $ZnSO_4$ recorded significantly higher grain yield (7.45 t ha^{-1}) over control (4.78 t ha^{-1}) (Afzal *et al.*, 2015). Arun *et al.* (2017) observed that in cowpea, seeds primed in $ZnSO_4$ 10^{-3} M solution registered significantly higher seed yield (1100.5 kg ha^{-1}). Iqbal *et al.* (2017) pointed out that priming of wheat seeds in 0.01 M B enhanced the grain yield significantly over control. Seed priming of green peas with 1 per cent $ZnSO_4$ solution for 12 h significantly improved the seed yield of green peas (Sharma and Parmar, 2018).

2.7.5 Effect of Seed Invigouration on Nutrient Uptake

Seed invigouration significantly improved Zn uptake in many crops. Lorenz (1994) reported that Zn application to seed significantly enhanced the Zn content in maize tissues over control. Ajouri *et al.* (2004) observed that barley seeds primed in Zn 10 mg kg^{-1} seed increased the Zn content from 94 to 216 mg kg^{-1}. Johnson *et al.* (2005) opined that nutripriming enhanced the Zn and B uptake in chickpea. Priming with optimal concentrations of Zn and B increased the Zn content from 40-60 to 500-800 mg kg^{-1} and B content from 10 to 80–100 mg kg^{-1}. In maize hybrid DK-919, seed priming with Zn 2 per cent followed by foliar application of Zn, 2 per cent improved the Zn content of grain (28.55 mg kg^{-1}) compared to control (19.88 mg kg^{-1}) (Afzal *et al.*, 2015). Munir *et al.* (2018) revealed that wheat seeds primed in ZnO nanoparticle 100 ppm significantly enhanced the Zn content in grain by 64 per cent, shoot by 65 per cent and root by 45 per cent over control.

Rehman *et al.* (2010) observed a linear increase in leaf and grain B content of fine grain aromatic rice with the increase in concentration of B in priming solution. Wheat seeds primed in 0.01 M B solution markedly enhanced the grain B content of grain by 27 per cent over control (Iqbal *et al.*, 2017). Ali *et al.* (2018) observed that nutripriming of wheat seeds with Zn and B enhanced the Zn and B content of grain.

Ghassemi-Golezani and Abdurrahman (2012) reported that nutripriming significantly enhanced the uptake of P, Zn, Fe, Mn and Cu by barley grain and straw. Maize seeds primed in P solution significantly enhanced the P uptake (Miraj *et al.*, 2013). Wiatrak (2013) reported that in winter wheat, polymer coating of seeds with Zn, Cu and Mn significantly improved the total N, P, K and Zn uptake. Maize seeds primed in 0.2 per cent P solution significantly enhanced the N uptake (Ali *et al.*, 2016). Nitrogen and P uptake was significantly enhanced due to seed priming in summer green gram (Gohil *et al.*, 2017). Nutripriming with KNO_3, KH_2PO_4, $Ca(NO_3)_2$, KCl and $Na_2S_2O_3$ significantly enhanced the NPK uptake of rice (Kushwaha *et al.*, 2018).

2.8 EFFECT OF TRICHODERMA SEED TREATMENT IN PULSES

Trichoderma is considered as a magical weapon against soil borne pathogens. Pan and Das (2011) observed that seed biopriming with mycelial preparation of *Trichoderma harzianum* effectively control collar and root rot in cowpea and enhanced the seed yield. Seed treatment of both *Trichoderma viride* and *Trichoderma harzianum* significantly reduced the wilt incidence and improved the seedling emergence in chick pea (Rehman *et al.*, 2013). Purushottam *et al.* (2014) revealed that seed treatment with *Trichoderma harzianum* significantly reduced the wilt disease by 26.7 per cent in chickpea and 25.9 per cent in lentil over control and enhanced the yield by 16.6 and 12.6 per cent, respectively in chickpea and lentil. Treating the seeds with *Trichoderma viride* 50 g kg^{-1} seed was very effective for the management of wilt and root rot disease in chick pea (Pandey *et al.*, 2017).

32

Materials and Methods

3. MATERIALS AND METHODS

The experiment entitled "Seed invigouration for yield enhancement in grain cowpea (*Vigna unguiculata* (L.) Walp)" was conducted during *Rabi* 2018 at Coconut Research Station, Balaramapuram, Kerala, India. The foremost goals of the investigation were to evaluate the effect of seed invigouration with zinc sulphate and borax on grain cowpea and to evaluate its effect along with *Trichoderma viride* on growth and yield of the crop.

3.1 GENERAL DETAILS

3.1.1 Location

The field experiment was conducted in the farm attached to Coconut Research Station (CRS), Balaramapuram, Kerala, located at 8° 22' 52" North latitude and 77° 1' 47" East longitude and at an altitude of 9 m above mean sea level.

3.1.2 Climate

A warm humid climate prevailed in the experimental site. The daily weather parameters *viz*., mean temperature, relative humidity (RH), rainfall and evaporation prevailed during the cropping period were recorded standard week wise and are given in Appendix 1 and are graphically presented in Fig. 1.

The rainfall received during the crop season extending from 10/11/2018 to 04/02/2019 was 175 mm. The mean maximum temperature of 31.8 °C and minimum temperature of 16.66 °C recorded during the crop season.

3.1.3 Cropping Season

The field experiment was conducted during 2018 *Rab*i season (10/11/ 2019 to 4/02/2019).

3.1.4 Soil

Soil of the experimental site was sandy loam in texture, red in colour, acidic in reaction, medium in organic carbon, N and P and low in K. The physical and chemical properties of the soil and are presented in Table 1.

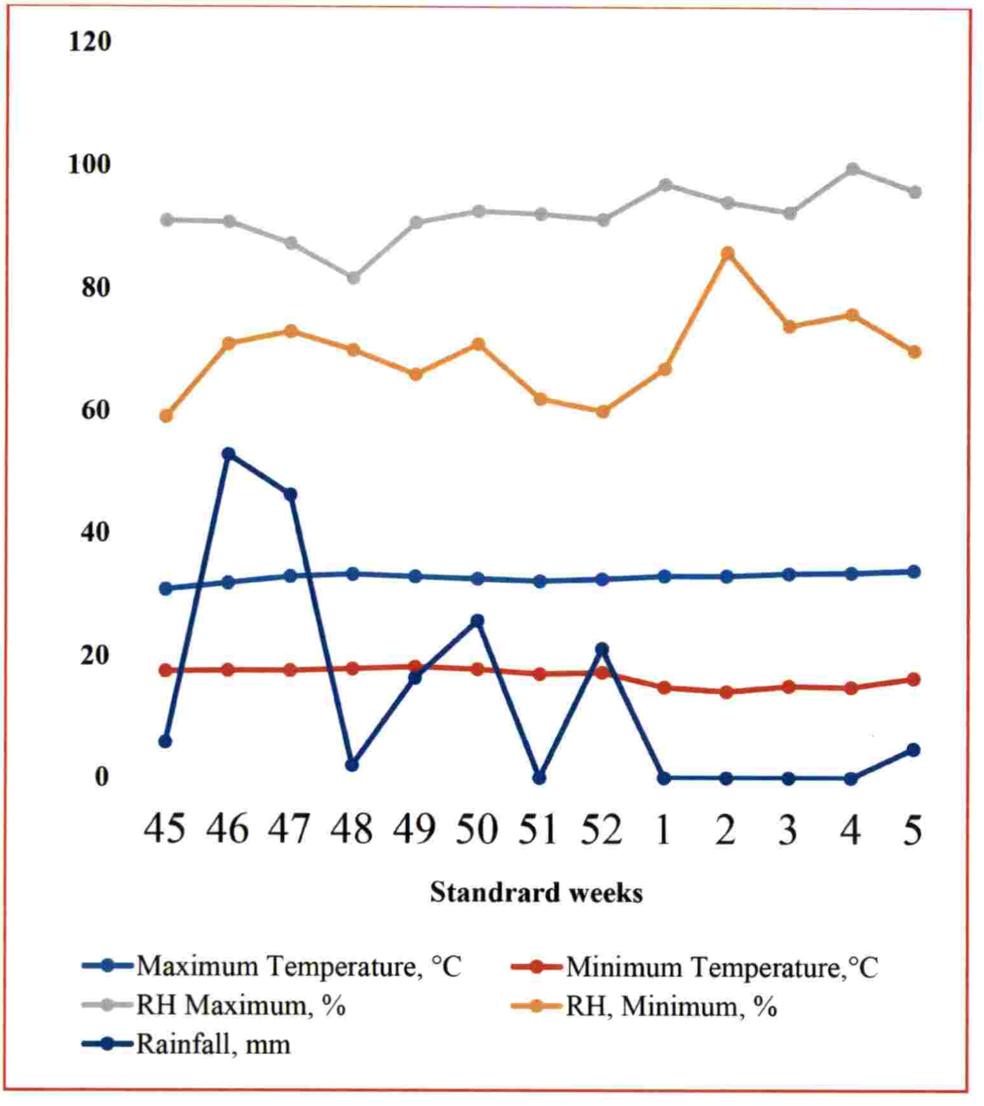


Fig.1. Weather data during the crop season (10/11/2019 to 4/02/2019)

Table 1. Physicochemical properties of the soil before the experiment

A. Mechanical Composition

Sl. No.	Fractions	Content in soil, per cent	Method
1.	Sand	66.43	Bouyoucous hydrometer method (Bouyoucous,1962)
2.	Silt	18.24	
3.	Clay	15.30	

B. Chemical Properties

Sl. No.	Parameters	Content	Method adopted
1.	Soil reaction	4.5 (Acidic)	pH meter (1:2.5 soil water ratio) (Jackson, 1973)
2.	EC, dSm^{-1}	0.10 (Normal)	Conductivity meter (1:2.5 soil water ratio) (Jackson, 1973)
3	Organic carbon, per Cent	0.650 (Medium)	Walkley and Black rapid titration method (Walkley and Black, 1934)
4	Available N, kg ha^{-1}	301.05 (Medium)	Alkaline permanganate method (Subbiah and Asija, 1956)
5	Available P, kg ha^{-1}	20.52 (Medium)	Bray colorimetric method (Jackson, 1973)
6	Available K, kg ha^{-1}	94.08 (Low)	Ammonium acetate method (Jackson, 1973)
7	Available Zn, mg kg^{-1} soil	0.457 (deficient)	HCl extraction and Atomic Absorption Spectrophotometry (Sims and Johnson, 1991)
8	Available B, mg kg^{-1} soil	0.018 (deficient)	Hot water extraction and colorimetry using Azomethine-H (Hesse, 1971)

3.1.5 Cropping History

The crop was raised in the interrow spaces of 55 years old coconut planted at a spacing of 7.6 m x 7.6 m having more than 70 per cent light transmission. The interrow space of coconut had banana crop during the previous season.

3.2. MATERIALS

3.2.1 Crop Variety

Bhagyalakshmy a short duration (90 days) variety with bold grains released from College of Horticulture, Vellanikkara, Thrissur, Kerala was used for the experiment. The variety is dwarf bushy type.

3.2.2 Source of Seed

The seeds of the Bhagyalakshmy for the experiments were procured from College of Horticulture, Vellanikkara, Thrissur.

3.2.3 Source of Trichoderma

Talc based formulation of *Trichoderma viride* having 2 x 10^6 CFU g^{-1} was procured from Department of Agricultural Microbiology, College of Agriculture, Vellayani,

3.2.4 Manures and Fertilizers

Dried farm yard manure (FYM) having a N content of 0.45 per cent, P_2O_5 content of 0.17 per cent and K_2O content of 0.5 per cent was used as organic manure. Urea (46 per cent N), rajphos (20 per cent P_2O_5) and muriate of potash (60 per cent K_2O were used as source of NPK for the experiment. Borax with 11. 4 per cent B and zinc sulphate with 21 per cent Zn were used source for seed priming and seed pelleting.

3.3 METHODS

3.3.1 EXPERIMENT NO. I: POT CULTURE EXPERIMENT TO STUDY THE INFLUENCE OF SEED INVIGOURATION METHODS ON GERMINATION AND SEEDLING VIGOUR OF GRAIN COWPEA

Pot culture experiment was conducted in the net house of Coconut Research Station, Balaramapuram for a period of eight days from 29/10/2018 to 05/11/2018. The variety used for the study was Bhagyalakshmy.

3.3.1.1 Design and Layout

Design : CRD

Replication : 3

Treatments : 13

3.3.1.2Treatment Details

T_1-Seed pelleting with $ZnSO_4$ 100 mg kg^{-1} seed

T_2-Seed pelleting with $ZnSO_4$ 200 mg kg^{-1}seed

T_3-Seed pelleting with borax 50 mg kg^{-1} seed

T_4-Seed pelleting with borax100 mg kg^{-1}seed

T_5-Seed pelleting with $ZnSO_4$ 100 mg + borax 50 mg kg^{-1}seed

T_6-Seed pelleting with $ZnSO_4$ 200 mg + borax 100 mg kg^{-1}seed

T_7-Seed priming with $ZnSO_4$ 0.025 per cent for 4 h

T_8-Seed priming with $ZnSO_4$ 0.05 per cent for 4 h

T_9-Seed priming with borax 0.01 per cent for 4 h

T_{10}-Seed priming with borax 0.02 per cent 4 h

T_{11}-Seed priming with $ZnSO_4$ 0.025 per cent + borax 0.01per cent for 4 h

T_{12}-Seed priming with $ZnSO_4$ 0.05 per cent+ borax 0.02 per cent for 4 h

T_{13}- control

For pelleting, $ZnSO_4$ and borax were mixed thoroughly with 10 per cent maida as adhesive @ 200 mL kg^{-1} seed, seeds were individually coated with the adhesive and shade dried. Seed priming was done by soaking the seeds in respective concentrations of $ZnSO_4$ and borax solutions for 4 h and shade dried to original moisture content. Pelleted and primed seeds were sown @ 25 seeds per pot filled with pure river sand. The crop was maintained in the pot for eight days and the following observations were recorded.

3.3.1.3 Observations on Seed Germination and Seedling Growth

3.3.1.3.1 Days to Germinate

Number of days taken by the seeds to germinate were counted and recorded. The observations were recorded up to eighth day after sowing.

3.3.1.3.2. Number of Seeds Germinated on Each Day

Number of seeds germinated on each day was counted and recorded. Count was recorded up to eighth day after sowing.

3.3.1.3.3 Seedling Root Length and Shoot Length

On the eighth day, five seedlings were randomly selected and uprooted without damaging the root system. Root and shoot length were measured from the five seedlings, average was worked out and expressed in cm.

3.3.1.3.4 Seedling Shoot and Root Fresh Weight

The root system was removed with a sharp knife from the same five seedlings selected for measuring the root and shoot length. The fresh weight of shoot and root were recorded separately, the average was worked out and expressed in g.

3.3.1.3.5 Seedling Shoot and Root Dry Weight

The samples were dried in hot air oven at 65 ± 5 °C to constant weight and the dry weight of shoot and root were recorded and expressed in g.

3.3.1.4 Germination Parameters

Based on the above observations, the following germination parameters were worked out.

Plate 1. General view of the pot culture experiment

3.3.1.4.1 Time to 50 Per cent Germination

Time to 50 per cent germination (T_{50}) was worked out based on the formula suggested by Farooq *et al.* (2005) and expressed in days.

3.3.1.4.2 Speed of Germination

Speed of germination (SG) was computed based on the formula described by Czabator (1962).

3.3.1.4.3 Mean germination time

Mean germination time (MGT) was calculated by the formula suggested by Orchard (1977) and expressed in days.

3.3.1.4.4 Mean Daily Germination

Mean daily germination (MDG) was worked out by using the formula proposed by (Czabator,1962) and expressed in no. day^{-1}.

3.3.1.4.5. Germination index

Germination index (GI) was calculated by the formula developed by Bench *et al.* (1991).

3.3.1.4.6 Germination Percentage

The germination percentage was calculated based on the formula proposed by ISTA (1985).

3.3.1.4.7 Germination Rate Index

Germination rate index (GRI) was worked out based on the formula developed by Esechi (1994).

3.3.1.4.8 Coefficient of Rate of Germination

Coefficient of rate of gemination (CRG) was calculated by the formula suggested by Jones and Sanders (1987).

3.3.1.4.9 Seedling Vigour Index I

Seedling vigour index I (SVI I) was worked out by the formula suggested by Abdul-baki and Anderson (1973).

3.3.1.4.10 Seedling Vigour Index II (SVI II)

Seedling vigour index II (SVI II) was also calculated by the formula developed by Abdul-baki and Anderson (1973).

3.3.1.5 Identifying the Best Seed Pelleting and Seed Priming Treatments

To identify two best seed pelleting and priming treatments, score of 1 to 13 were assigned to different parameters *viz*., time to 50 per cent germination, speed of germination, mean germination time, mean daily germination, germination percentage, coefficient of rate of germination, germination index, germination rate index, vigour index I and vigour index II. Score 1 was assigned to the best treatment and 13 to the least one. Two best seed pelleting and priming treatments were selected based on the total score obtained. Two seed pelleting treatments which scored lower score among the six seed pelleting treatments and two best seed priming treatments which scored lower score among the six priming treatments were selected for the field experiment.

3.3.2 EXPERIMENT II. FIELD EXPERIMENT TO STUDY THE EFFECT OF SEED INVIGOURATION TECHNIQUES ON YIELD ENHANCEMENT IN GRAIN COWPEA

3.3.2.1 Design and Layout

Design	: RBD
Treatments	: 9
Replication	: 3
Season	: *Rabi* 2018
Spacing	: 30 cm x 15 cm
Gross plot size	: 3 m x 3 m
Net plot size	: 1.8 m x 2.4 m
Location	: Coconut Research Station, Balaramapuram

3.3.2.2 Treatment Details

T_1: Seed pelleting with borax 50 mg kg^{-1} soil

T_2: Seed pelleting with borax 100 mg kg^{-1} soil

T_3: Seed priming with $ZnSO_4$ 0.025 per cent for 4 h

T_4: Seed priming with $ZnSO_4$ 0.05 per cent for 4 h

T_5: T_1 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed

T_6: T_2 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed

T_7: T_3 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed

T_8: T_4 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed

T_9: Control

The crop was raised as per the POP recommendations of Kerala Agricultural University (KAU, 2016). Seed treatment with *Trichoderma viride* was done just before sowing the seeds.

3.3.2.3 Preparatory Cultivation

The experimental area was ploughed to fine tilth with a garden tiller. After removing the weeds and stubbles, field was levelled. Then the field was arranged into 27 plots each having a gross plot size of 3 m x 3 m and individual bunds were taken around each plot.

3.3.2.4 Lime Application

At the time of first ploughing, lime @ 250 kg ha^{-1} was uniformly applied to the experimental plots.

3.3.2.5 Manure and Fertilizer Application

At the time of second ploughing, dried powdered FYM having 0.47 per cent N, 0.15 per cent P_2O_5 and 0.50 per cent K_2O @ 20 t ha^{-1} was applied. Chemical fertilizers were applied @ 20:30:10 kg NPK ha^{-1}. Half N, full phosphorus (P) and potassium (K) were applied before sowing the seeds and remaining half N was applied at 20 days after sowing (DAS).

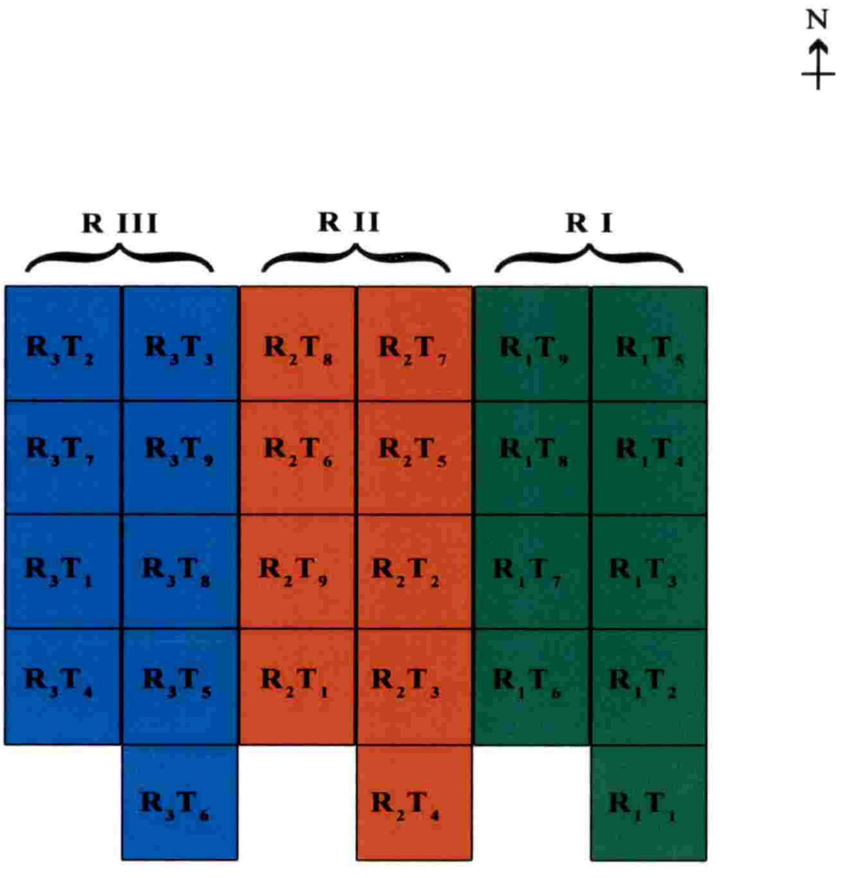


Fig.2. Layout of the experimental field

Plate 2. General view of the experimental field

3.3.2.6 Seeds and Sowing

Single seed as per the treatment were sown at a spacing of 30 cm x 15 cm. After sowing the seeds, a light irrigation was given to ensure uniform germination. Germination count was recorded on eighth day after sowing.

3.3.2.7 After Cultivation

After taking the germination count at eighth day, gap filling was done by sowing the seeds as per the treatment. Manual weeding was carried out to control the weeds. First weeding was carried out at 15 DAS and second weeding at 30 DAS.

3.3.2.8 Plant Protection

For the control of anthracnose disease observed at 20 DAS, SAAF (carbendazim 12 per cent + mancozeb 63 per cent WP) was sprayed @ 3 g L^{-1}. Minor incidence of maruca pod borer was observed at the flowering stage. It was controlled by spraying coragen 3 ml 10 L^{-1} (chlorantraniliprole 18.5 per cent EC).

3.3.2.9 Harvest

Harvesting was done by picking the mature pods. Three harvest were taken during the crop period and harvesting was completed on 86th day after sowing. The border rows and observation plants were harvested separately. The pods harvested from the net plot area were sun dried, threshed, seeds were separated, winnowed and the seed yield was recorded treatment wise. Haulm yield from the net plot area were also sun dried, weighed and recorded the yield treatment wise.

3.3.3 OBSERVATIONS ON CROP

3.3.3.1 Field Emergence Percentage

For calculating the field emergence percentage, germination count was recorded on eighth day and field emergence percentage was calculated by

$$\text{Field emergence percentage} = \frac{\text{Total number of seeds emerged on the eighth day}}{\text{Total number of seeds sown}} \times 100$$

3.3.3.2 Growth Parameters

From the net plot area five plants were randomly selected and tagged for recording the observations on growth parameters *viz*., plant height, number of green leaves per plant and branches per plant.

3.3.3.2.1 Plant Height

Height of the crop was measured from the ground level to the tip of the plant from the tagged plants at 30 DAS, 60 DAS and at harvest. The average was worked out and expressed in cm.

3.3.3.2.2 Number of Branches Per Plant

Number of branches per plant was recorded from the five tagged plants at 30 DAS, 60 DAS and at harvest and the average was worked out for each treatment.

3.3.3.2.3 Number of Green Leaves

Number of green leaves in the tagged plants were counted at 30 DAS and 60 DAS and the average was worked out.

3.3.3.2.4 Dry Matter Production

For the determination of DMP, randomly selected five plants and uprooted from outside the net plot area leaving the border rows at 30 DAS, 60 DAS and at harvest. The plant samples were initially air dried for two days and then oven dried at 65 ± 5 °C to constant weight. The average was worked out and expressed as g per plant.

3.3.3.3 Physiological Parameters

3.3.3.3.1 Leaf Area Index

The leaf area was measured by graphical method and expressed in cm^2 at 30 DAS and 60 DAS. Leaf area index (LAI) was worked out by the formula described by Watson (1952).

3.3.3.3.2 Chlorophyll Content

DMSO (dimethyl sulphoxide) method suggested by Yoshida *et al.* (1976) was adopted for the determination of chlorophyll content of the leaves at 30 DAS and 60 DAS.

3.3.3.3.3 Crop Growth Rate

Crop growth rate (CGR) was calculated by the formula proposed by Watson (1958) at two stages, from 30 DAS to 60 DAS and from 60 DAS to harvest.

3.3.3.3.4 Relative Growth Rate

Relative growth rate (RGR) was calculated by the formula suggested by Evans (1972) at two growth stages, from 30 DAS to 60 DAS and from 60 DAS to harvest.

3.3.3.4 Nodule Parameters

Nodulation was assessed at 50 per cent flowering. Five plants from outside the net plot area were randomly selected and uprooted without causing any damage to the roots. Soil adhered to the root portion were carefully removed by washing the roots in clean water. After the removal of soil, nodules were carefully detached from the roots. Total number of nodules, effective nodules and fresh weight of nodules were recorded from five plants treatment wise. The average was worked out and expressed as number per plant and g per plant, respectively. Then the nodules were transferred to a small brown paper cover, oven dried at 65 ± 5 °C to a constant weight and recorded the dry weight of nodules and expressed as g per plant.

3.3.3.5 Yield Parameters and Yield

3.3.3.5.1 Days to 50 Per cent Flowering

Days to 50 per cent flowering was recorded by counting the number of days from sowing to 50 per cent of the plants in each treatment plot produced first flower and was expressed in days.

3.3.3.5.2 Number of Pods Per Plant

Number of pods harvested from the tagged plants in each treatment were counted individually and the average was worked out and expressed as number of pods per plant.

3.3.3.5.3 Number of Seeds Per Pod

Five pods were randomly selected from the tagged plants in each treatment. Seeds were separated from the pods and counted. The mean number of seeds per pod was worked out by dividing the total number of seeds by number of pods.

3.3.3.5.4 Pod Length

Pod length was measured from five pods randomly selected from the observation plants. Pod length was measured from the base to the tip of the plant, the average was worked out and expressed in cm.

3.3.3.5.5 Pod Girth

Pod girth was measured from the same five pods selected for measuring the pod length. Pod girth was measured from the middle of the pod using a thread and scale and expressed in cm.

3.3.3.5.6 Pod Weight Per Plant

Pods were harvested separately from five observation plants in each treatment, sun dried, weighed and the average was arrived at and expressed in g.

3.3.3.5.7 Seed Yield Per Plant

Pods harvested from five observation plants in each treatment were sun dried, shelled and cleaned separately. After drying and cleaning, the seed weight from each plant was recorded and average was arrived at and expressed in g.

3.3.3.5.8 Total Seed Yield ha^{-1}

Pods harvested from the net plot area in each treatment were sun dried, shelled and cleaned. The seed weight from five plants from which observations

49

were recorded was also added for computing the seed yield per ha. Seed yield ha^{-1} was computed from net plot yield and expressed in kg ha^{-1}.

3.3.3.5.9 Haulm Yield Per Plant

After the harvest of pods, the observation plants were uprooted from each treatment plot, dried in sun, weighed individually, average was worked out and expressed as g per plant.

3.3.3.5.10 Total Haulm Yield ha^{-1}

Plants from the net plot area of each treatment were uprooted after the harvest of the pods, dried in sun and weighed separately. Total haulm yield ha^{-1} was worked out from the net plot haulm yield and expressed in kg ha^{-1}.

3.3.3.5.11 Harvest Index

The harvest index (HI) was calculated by the formula suggested by Donald and Hamblin (1976).

3.3.4 CHEMICAL ANALYSIS

3.3.4.1 Soil Analysis

For initial soil sample analysis, soil samples were drawn to a depth of 15 cm from four different spots in the experiment plot, shade dried, ground and composite sample was prepared by quartering. After the harvest of crop also, composite soil sample was drawn from each treatment plot for the analysis of organic carbon, available N, P, K, Zn and B.

3.3.4.1.1 Organic Carbon

Organic carbon content of soil was determined by rapid titration method (Walkley and Black, 1934) and expressed in percentage.

3.3.4.1.2 Available Nitrogen

Alkaline potassium permanganate method developed by Subbiah and Asija (1956) was adopted for the determination of available N content of soil.

3.3.4.1.3 Available Phosphorus

Available P status of post-harvest soil was determined by Dickman and Brays molybdenum blue method (Jackson, 1973).

3.3.4.1.4 Available Potassium

Available K status of post-harvest soil was determined by the method suggested by Jackson (1973).

3.3.4.1.5 Available Zinc

The method developed by Sims and Johnson (1991) was adopted for the determination of available Zn status of post-harvest soil.

3.3.4.1.6 Available Boron

Available B status of post-harvest soil was determined by the method described by Hesse (1971).

3.3.4.2 Plant Analysis

The grain and haulm samples at harvest stage were analysed for the total N, P, K, Zn and B content. The samples were sun dried initially for two days and then dried in hot air oven at 65 ± 5 °C to constant weight, ground and used for analysis. The required quantities of samples were weighed out accurately, subjected to acid extraction and N, P, K, Zn and B content were determined.

3.3.4.2.1 Total N Content

The method developed by Jackson (1973) was used for the determination of Total N content of haulm and seed.

3.3.4.2.2 Total P Content

Total P content of haulm and seed were estimated by the method described by Jackson (1973).

3.3.4.2.3 Total K Content

Total K content of haulm and seed were also determined by the method proposed by Jackson (1973).

3.3.4.2.4 Total Zn Content

Total Zn content was estimated by the method described by Lindsay and Norvell (1978).

3.3.4.2.5 Total B Content

Total B content was determined by azomethine-H calorimetric method developed by Wolf (1971).

3.3.4.3 Uptake of Nutrients

Nutrient uptake was worked out by multiplying the nutrient content with the respective dry matter production and expressed in kg ha^{-1}. Uptake by grain and haulm were determined separately and added both to get the total uptake of N, P, K, Zn and B by the crop.

3.3.5 QUALITY PARAMETERS

3.3.5.1 Crude Protein Content

Protein content was estimated from N content of the grain and multiplied with factor 6.25 Simpson *et al.* (1965).

3.3.6 ECONOMIC ANALYSIS

The economics was worked out based on the cost of cultivation and the prevailing market price of the produce.

3.3.6.1 Net Income

Net income was computed using the formula

Net income (₹ ha^{-1}) = Gross income - Cost of cultivation

3.3.6.2 Benefit Cost Ratio

Benefit cost ratio was computed using the formula

$$\text{B: C ratio} = \frac{\text{Gross Income}}{\text{Cost of cultivation}}$$

3.3.7 PEST AND DISEASE INCIDENCE

Maruca pod borer was observed at the flowering stage, but it was below the economic threshold level and hence, scoring was not done. The major disease observed was anthracnose. It was observed at the seedling stage (20 DAS). Severity of disease incidence was assessed by following 0-9 scale developed by Mayee and Datar (1986).

Percentage disease index was calculated by following the formula suggested by Wheeler (1969).

$$\text{Per cent disease index} = \frac{\text{Total sum of numerical rating}}{\text{No. of leaves examined x maximum grade value}} \times 100$$

3.3.8 STATISTICAL ANALYSIS

Analysis of Variance technique for RBD (Cochran and Cox, 1965) was adopted for the statistical analysis of the experimental data and the significance was tested using F test. The data which required transformation were appropriately transformed and analysed. Wherever the F values were found significant, critical difference was calculated at five per cent probability level.

Results

4. RESULTS

The investigation on "Seed invigouration for yield enhancement in grain cowpea (*Vigna unguiculate* (L.) Walp)" was carried out at Coconut Research Station, Balaramapuram during November 2018 to February 2019. The objectives of the experiment were to evaluate the influence of seed invigouration with zinc sulphate and borax on grain cowpea and to evaluate its effect along with *Trichoderma viride* on growth and yield of grain cowpea. The results obtained after the statistical analysis of the data are presented in this chapter.

4.1 EXPERIMENT NO. I: POT CULTURE EXPERIMENT TO STUDY THE INFLUENCE OF SEED INVIGOURATION METHODS ON GERMINATION AND SEEDLING VIGOUR OF GRAIN COWPEA

4.1.1 Germination Parameters

Data on germination parameters *viz.*, GP, MDG, SI, MGT, GI, CRG and GRI) were statistically analysed and presented in Table 2.

4.1.1.1 Germination Percentage

Germination percentage was statistically influenced by seed invigouration treatments. Except T_{11} (seed priming with $ZnSO_4$ 0.025 percent + borax 0.01 percent for 4 h), all the other seed invigouration treatments registered higher germination percentage than control. The treatment, T_3 (seed pelleting with borax 50 mg kg^{-1} seed) recorded the highest germination percentage (88 percent) and it was statistically comparable with all other seed invigouration treatments except T_{11} (seed priming with $ZnSO_4$ 0.025 percent + borax 0.01 percent for 4 h) and T_{12} (seed priming with $ZnSO_4$ 0.05 percent + borax 0.02 percent for 4 h). The lowest germination percentage was recorded in T_{11}.

Table 2. Effect of seed invigouration treatments on germination parameters

Treatments	Germination percentage (%)	Mean daily germination (no. day^{-1})	Speed of germination	Mean germination time (days)	Germination index	Coefficient of rate of germination	Germination rate index	Time to 50 per cent germination (T_{50}) (days)
T_1	78.67 (62.61)	2.46	5.53	3.74	103.33	26.75	22.14	3.33
T_2	76.00 (60.98)	2.38	5.30	3.74	99.00	26.95	21.19	3.33
T_3	88.00 (69.88)	2.75	6.41	3.61	119.67	27.74	25.65	3.00
T_4	86.67 (69.41)	2.71	6.34	3.55	118.00	28.36	24.79	3.00
T_5	86.67 (68.60)	2.71	6.33	3.57	117.33	28.25	25.31	3.33
T_6	76.00 (60.82)	2.38	5.29	3.71	99.00	26.97	21.17	3.33
T_7	86.67 (68.89)	2.71	6.25	3.68	115.33	27.31	24.32	3.00
T_8	85.33 (67.96)	2.67	6.43	3.48	118.00	28.82	25.72	3.00
T_9	77.33 (61.97)	2.42	5.28	3.95	97.67	25.32	21.11	3.33
T_{10}	84.00 (66.86)	2.63	6.09	3.55	110.00	28.23	24.31	3.67
T_{11}	62.67 (52.40)	1.96	4.65	3.52	86.00	28.58	18.60	3.33
T_{12}	72.33 (58.94)	2.29	5.38	3.60	99.00	27.81	20.62	3.00
T_{13}	72.00 (58.18)	2.25	4.89	3.91	83.67	25.61	19.43	3.67
SE m (±)	3.21	0.14	0.36	0.10	7.53	1.08	0.87	0.26
CD (0.05)	9.368	0.401	1.049	0.289	22.004	NS	2.542	NS

Values in parentheses are transformed values (arc sine transformation), NS-not significant

4.1.1.2 Mean daily germination

Mean daily germination was also significantly influenced by seed priming and pelleting treatments. Similar to that of germination percentage, T_3 (seed pelleting with borax 50 mg kg^{-1} seed) registered higher MDG (2.75) which was statistically comparable with all seed invigouration treatments except T_{11} (seed priming with $ZnSO_4$ 0.025 percent + borax 0.01 percent for 4 h) and T_{12} (seed priming with $ZnSO_4$ 0.05 percent + borax 0.02 percent for 4 h). The lowest mean daily germination (1.96) was recorded in T_{11}.

4.1.1.3 Speed of Germination

Speed of germination was also significantly influenced by seed invigouration treatments. The treatment T_8 (seed priming with $ZnSO_4$ 0.05 percent for 4 h) recorded the highest SG (6.43) among the seed pelleting and priming treatments and it was statistically comparable with T_3 (seed pelleting with borax 50 mg kg^{-1} seed), T_5 (seed pelleting with $ZnSO_4$ 100 mg + borax 50 mg kg^{-1} seed), T_4 (seed pelleting with borax 100 mg kg^{-1} seed), T_7 (seed priming with $ZnSO_4$ 0.05 percent for 4 h), T_{10} (seed priming with borax 0.02 percent for 4 h) and T_1 (seed pelleting with $ZnSO_4$ 100 mg kg^{-1} seed). The treatment T_{11} (seed priming with $ZnSO_4$ 0.025 percent + borax 0.01 percent for 4 h) registered the lowest SG and it was statistically comparable with control (T_{13}).

4.1.1.4 Mean Germination Time

Mean germination time was also significantly influenced by seed pelleting and priming treatments. Among the seed pelleting and priming treatments, T_8 (seed priming with $ZnSO_4$ 0.05 percent for 4 h) registered the lowest MGT (3.48 days) which was statistically comparable with all other treatments except T_9 (seed priming with borax 0.01 percent for 4 h) and control (T_{13}). The highest MGT (3.95 days) was recorded in T_9.

4.1.1.5 Germination Index

Seed pelleting and priming treatments significantly influenced the germination index. The treatment T_3 (seed pelleting with borax 50 mg kg^{-1} seed) registered the highest GI (119.67) among the treatments and it was statistically comparable with all seed invigouration treatments, except T_{11} (seed priming with $ZnSO_4$ 0.025 percent + borax 0.01 percent for 4 h). The lowest GI (83.67) was recorded by T_{13} (control) and it was statistically comparable with T_{11} (seed priming with $ZnSO_4$ 0.025 percent + borax 0.01 percent for 4 h).

4.1.1.6 Coefficient of Rate of Germination

Coefficient of rate of germination was not statistically influenced by seed pelleting and priming treatments. Though statistically non-significant, T_8 (seed priming with $ZnSO_4$ 0.05 percent for 4 h) registered the highest CRG and the lowest by T_9 (seed priming with borax 0.01 percent for 4 h).

4.1.1.7. Germination Rate Index

Germination rate index was significantly influenced by seed priming and pelleting treatments. All the seed invigouration treatments recorded higher GRI than control. The treatment T_8 (seeds priming with 0.05 percent $ZnSO_4$ for 4 h) registered the highest GRI among the seed pelleting and priming treatments and it was statistically on par with T_3 (seed pelleting with borax 50 mg kg^{-1} seed), T_4 (seed pelleting with borax 100 mg kg^{-1} seed), T_5 (seed pelleting with $ZnSO_4$ 100 mg + borax 50 mg kg^{-1} seed), T_7 (seed priming with $ZnSO_4$ 0.025 percent for 4 h) and T_{10} (seed priming with borax 0.02 percent for 4 h). The treatment T_{11} (seed priming with $ZnSO_4$ 0.025 percent + borax 0.01 percent for 4 h) recorded the lowest GRI (18.60) among the treatments.

4.1.1.8 Time to 50 Percent Germination (T_{50})

Time to 50 percent germination was not statistically influenced by seed pelleting and seed priming treatments. Though not significant, T_3 and T_4 (seed pelleting with borax 50 and 100 mg kg^{-1} seed) , T_7 and T_8 (seed priming with $ZnSO_4$ 0.025 and 0.05 percent for 4 h) and T_{12} (seed priming with $ZnSO_4$ 0.05 percent + borax 0.02 percent for 4 h) recorded only three days to attain 50 percent germination and were the lowest among the seed invigouration treatments and control.

4.1.2 Seedling Growth and Vigour Index

Results of seedling growth and vigour index are presented in Table 3.

4.1.2.1 Seedling Shoot Length

Seedling shoot length was significantly influenced by seed priming and pelleting treatments. Among the treatments, T_3 (seed pelleting with borax 50 mg kg^{-1} seed) recorded the highest shoot length (17.48 cm) and the control registered the lowest seedling shoot length (14.39).

4.1.2.2 Seedling Root Length

Seedling root length was also significantly influenced by seed pelleting and priming treatments. The treatment T_1 (seed pelleting with $ZnSO_4$ 100 mg kg^{-1} seed) recorded seedlings with highest root length (9.87 cm) and it was statistically on par with T_5 (seed pelleting with $ZnSO_4$ 100 mg + borax 50 mg kg^{-1} seed), T_3 (seed pelleting with borax 50 mg kg^{-1} seed) and T_{12} (Seed priming with $ZnSO_4$ 0.05 percent+ borax 0.02 percent for 4 h). The control treatment (T_{13}) recorded significantly lower root length (5.86 cm) among the treatments.

4.1.2.3 Seedling Shoot Fresh Weight

Fresh weight of seedlings was also significantly influenced by the seed pelleting and priming treatments. Among the treatments, T_5 (seed pelleting with $ZnSO_4$ 100 mg + borax 50 mg kg^{-1} seed) registered the highest seedling shoot fresh weight (1.096 g) and it was statistically on par with other seed invigouration treatments except, T_{12} (seed priming with $ZnSO_4$ 0.05 percent + borax 0.02 percent for 4 h) and T_6 (seed pelleting with $ZnSO_4$ 200 g + borax 100 mg kg^{-1} seed) . The control (T_{13}) registered the lowest seedling shoot fresh weight among the treatments.

59

Table 3. Effect of seed invigouration treatments on seedling growth and vigour index of grain cowpea

Treatments	Shoot length (cm)	Root length, (cm)	Shoot fresh weight (g)	Shoot dry weight (g)	Root fresh weight (g)	Root dry weight (g)	Seedling vigour index I	Seedling vigour index II
T_1	15.53	9.87	1.007	0.596	0.150	0.090	1993	53.79
T_2	16.33	7.02	0.999	0.684	0.151	0.119	1754	60.35
T_3	17.48	8.58	1.004	0.583	0.160	0.111	2292	61.36
T_4	16.42	8.34	1.064	0.577	0.154	0.138	2174	62.04
T_5	16.07	8.71	1.096	0.577	0.172	0.136	2153	60.92
T_6	15.40	6.37	0.907	0.570	0.137	0.117	1659	50.49
T_7	16.33	8.06	1.084	0.679	0.162	0.131	2112	67.83
T_8	16.44	7.79	1.055	0.646	0.175	0.126	2069	65.56
T_9	16.29	8.10	1.015	0.488	0.201	0.105	1886	47.88
T_{10}	14.81	7.35	1.044	0.628	0.152	0.102	1871	60.56
T_{11}	14.63	7.09	1.017	0.539	0.157	0.075	1354	39.11
T_{12}	15.02	8.88	0.966	0.586	0.135	0.110	1751	51.12
T_{13}	14.39	5.86	0.869	0.417	0.112	0.100	1460	37.32
SE m (±)	0.46	0.45	0.04	0.03	0.01	0.01	120	2.47
CD (0.05)	1.339	1.323	0.116	0.092	0.029	0.020	350.9	7.205

4.1.2.4 Seedling Shoot Dry Weight

Seedling shoot dry weight was also significantly influenced by seed priming and seed pelleting treatments. The treatment T_2 (seed pelleting with $ZnSO_4$ 200 mg kg^{-1} seed) recorded the highest seedling shoot dry weight (0.684 g) and was statistically on par with T_7 (seed priming with $ZnSO_4$ 0.025 per cent for 4 h), T_4 (seed pelleting with borax 100 mg kg^{-1} seed), T_{10} (seed priming with borax 0.02 per cent for 4 h) and T_1 (seed pelleting with $ZnSO_4$ 100 mg kg^{-1} seed). Control registered seedlings with the lowest shoot dry weight, however it was statistically comparable with T_9 (seed priming with borax 0.01 per cent for 4 h).

4.1.2.5 Seedling Root Fresh Weight

Seed invigouration treatments have significant effect on seedling root fresh weight. The treatment T_9 (seed priming with borax 0.01 per cent for 4 h) recorded the highest seedling fresh root weight (0.201 g) and it was statistically on par with T_8 (seed priming with $ZnSO_4$ 0.05 per cent for 4 h) and T_5 (seed pelleting with borax 100 mg kg^{-1} seed). The control registered the lowest seedling fresh root weight (0.112 mg).

4.1.2.6 Seedling Root Dry Weight

Seedling root dry weight was also significantly influenced by seed invigouration methods. The treatment T_4 (seed pelleting with borax 100 mg kg^{-1} seed) registered the highest seedling root dry weight (0.138 g) and it was statistically on par with T_5 (seed pelleting with $ZnSO_4$ 100 mg + borax 50 mg kg^{-1} seed), T_7 (seed priming with $ZnSO_4$ 0.025 per cent for 4 h), T_8 (seed priming with $ZnSO_4$ 0.05 per cent for 4 h) and T_2 (seed pelleting with $ZnSO_4$ 200 mg kg^{-1} seed). The treatment T_{11} (seed priming with $ZnSO_4$ 0.025 per cent + borax 0.01 per cent for 4 h) registered the lowest seedling root dry weight and it was statistically on par with T_1 (seed pelleting with $ZnSO_4$ 100 mg kg^{-1} seed).

4.1.2.7 Seedling Vigour Index I

Seedling vigour index I was also significantly influenced by the seed pelleting and priming treatments. Among the seed pelleting and priming treatments, T_3 registered the highest SVI I (2292) and it was statistically comparable with T_3 (seeds pelleting with borax 50 kg^{-1} seed) T_4 (seeds pelleting with borax 100 kg $seed^{-1}$), T_5 (seed pelleting with $ZnSO_4$ 100 mg + borax 50 mg kg^{-1} seed), T_7 (seeds priming with $ZnSO_4$ 0.025 percent for 4 h), T_8 (seeds priming with $ZnSO_4$ 0.05 percent for 4 h) and T_1 (seeds pelleting with $ZnSO_4$ 100 mg kg^{-1} seed). The treatment T_{11} recorded the lowest SVI (1354) and it was statistically comparable with T_{12} (seeds priming with $ZnSO_4$ 0.05 percent + borax 0.02 percent for 4 h) and control (T_{13}).

4.1.2.8. Seedling Vigour Index II

Seedling vigour index II was also significantly influenced by seed pelleting and priming treatments. Among the seed invigouration treatments, T_7 (seed priming in 0.025 percent $ZnSO_4$ for 4 h) registered the highest SVI II (67.83) and it was statistically comparable with T_8 (seed priming in 0.05 percent $ZnSO_4$ for 4 h), T_4 (seeds pelleting with borax 100 mg kg^{-1} seed), T_3 (seed pelleting with borax 50 mg kg^{-1} seed) and T_5 (seeds pelleting with $ZnSO_4$ 100 mg kg^{-1} seed). The lowest SVI II (37.32) was recorded by control.

4.1.2.3 Scoring to Identify the Best Seed Pelleting and Seed Priming Treatments for Field Experiment (Table 4)

Scores of 1 to 13 were assigned to each germination parameter with the score of 1 was assigned to the best treatment and 13 to the treatment performed least (Table 4). Based on the total scores obtained, T_3 (seed pelleting with borax 50

Table 4. Scoring to identify the best seed pelleting and priming treatments for field experiment

Treatments	Germination percentage	Mean daily germination	Speed of germination	Mean germination time	Germination index	Coefficient of rate germination	Germination rate index	T_{50}	SVI I	SVI II	Total Score
T_1	7	5	7	9	6	11	8	2	6	8	69
T_2	10	7	8	9	9	10	9	2	9	7	80
T_3	1	1	2	5	1	7	2	1	1	4	25
T_4	2	2	3	3	1	3	4	1	2	3	24
T_5	4	2	4	4	3	4	3	2	4	5	35
T_6	10	7	3	8	7	9	7	2	11	10	74
T_7	3	2	7	7	5	8	5	1	3	1	42
T_8	5	3	5	1	1	1	1	1	5	2	25
T_9	8	6	10	11	10	13	10	2	7	11	88
T_{10}	6	4	5	3	6	5	6	3	8	6	52
T_{11}	13	10	12	2	13	2	13	2	13	12	92
T_{12}	11	9	7	6	11	6	11	1	10	9	81
T_{13}	12	8	11	10	12	12	12	3	12	13	105

SVI I- seedling vigour index I, SVI II- seedling vigour index II mg kg^{-1} seed) and T_4 (seed pelleting with borax100 mg kg^{-1}seed) which scored lower scores (25 and 24, respectively) were selected as the two best seed pelleting treatments and among the priming treatments, T_8 (seed priming with $ZnSO_4$ 0.025 percent for 4 h) and T_7 (seed priming with $ZnSO_4$ 0.05 percent for 4 h) which scored lesser scores of 25 and 42, respectively were selected as the best seed priming treatments for field experimentation.

4.2 EXPERIMENT NO.II. FIELD EXPERIMENT TO STUDY THE EFFECT OF SEED INVIGOURATION TECHNIQUES ON YIELD ENHANCEMENT IN GRAIN COWPEA

4.2.1 Field Emergence Percentage

Field emergence percentage was significantly influenced by seed invigouration treatments (Table 5). The treatment T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h) recorded the highest field emergence percentage (97.44) and it was statistically comparable with all seed invigouration treatments. The control recorded the lowest field emergence percentage (76.58).

4.2.2 Growth Parameters

4.2.2.1 Plant Height

Data on plant height of grain cowpea at 30 DAS, 60 DAS and at harvest are furnished in Table 6. Results revealed that plant height was not significantly influenced by seed invigouration treatments at all the three stages.

4.2.2.2Number of Branches Per Plant

Effect of seed invigouration treatments on number of branches per plant are presented in Table 7.

Seed invigouration treatments significantly influenced the branches per plant at 30 DAS, 60 DAS and at harvest. Seeds primed in $ZnSO_4$ 0.05 percent for 4 h (T_4) and seeds primed in $ZnSO_4$ 0.025 percent for 4 h + *Trichoderma viride* seed treatment 10 g kg^{-1} seed (T_7) recorded higher number of branches (3.33) and these two treatments were statistically with other seed invigouration treatments except seed pelleted with borax 50 mg kg^{-1} seed (T_1) at 30 DAS.

At 60 DAS also, T_7 recorded higher number of branches (3.60) and it was statistically comparable with T_1 and T_2 (seeds pelleted with borax 50 and 100 mg kg^{-1} seed) and T_3 and T_4 (seeds primed in $ZnSO_4$ 0.025 and 0.05 percent for 4 h).

The treatment T_7 recorded higher number of branches at harvest and it was on par with T_4 and T_2.

The lowest number of branches per plant was recorded by the control (T_9) at all the three stages of observation.

4.2.2.3 Number of Green Leaves Per plant

The influence of seed invigouration treatments on number of green leaves per plant at 30 and 60 DAS are given in Table 7.

Results revealed that seed invigouration treatments significantly influenced green leaves per plant at both stages of observation. At 30 DAS, T_4 (seeds primed in $ZnSO_4$ 0.05 percent) was found to be superior (13.27) and the lowest number of green leaves was observed in the control treatment (T_9) which was significantly inferior to other treatments.

At 60 DAS also, T_4 was found to be superior (19.27) and it was statistically on par with T_3 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h), T_7 (seeds primed in 0.025 percent ZnSO4 for 4 h + *Trichoderma viride* 10 g kg^{-1} seed) and T_8 (seeds primed in 0.025 percent $ZnSO_4$ + *Trichoderma viride* 10 g kg^{-1} seed). Lesser number of green leaves per plant (14.87) was registered in the control treatment.

4.2.2.4 Dry Matter Production

Data related to the influence of seed invigouration treatments on dry matter production per plant is presented in Table 8. Seed invigouration treatments had significant effect on dry matter production per plant at 30 DAS, 60 DAS and at harvest.

65

Table 5. Effect of seed invigouration treatments on field emergence, %

Treatments	Field emergence	
T_1-Seed pelleting with borax 50 mg kg^{-1} seed	95.73	(79.18)
T_2-Seed pelleting with borax 100 mg kg^{-1} seed	96.58	(79.46)
T_3-Seed priming with $ZnSO_4$ 0.025 per cent for 4 h	96.58	(79.84)
T_4-Seed priming with $ZnSO_4$ 0.05 per cent for 4 h	97.44	(81.66)
T_5-Seed pelleting with borax 50 mg kg^{-1} seed + *Trichoderma viride* seed treatment10 g kg^{-1} seed	92.31	(75.30)
T_6-Seed pelleting with borax 100 mg kg^{-1} seed + *Trichoderma viride* seed treatment 10 g kg^{-1} seed	96.15	(79.32)
T_7-Seed priming with $ZnSO_4$ 0.025 per cent for 4h + *Trichoderma viride* seed treatment 10 g kg^{-1} seed	93.16	(75.44)
T_8-Seed priming with $ZnSO_4$ 0.05 per cent for 4h + *Trichoderma viride* seed treatment10 g kg^{-1} seed	92.31	(75.30)
T_9 -Control	76.58	(61.14)
SEm (±)		2.95
CD (0.05)		8.927

Table 6. Effect of seed invigouration treatments on plant height of grain cowpea, cm

Treatments	Plant height		
	30 DAS	60 DAS	At harvest
T_1	47.31	58.06	58.96
T_2	46.42	56.27	57.48
T_3	44.05	59.48	60.02
T_4	47.57	56.73	60.75
T_5	41.68	56.79	57.26
T_6	43.45	58.34	59.60
T_7	47.02	61.65	62.08
T_8	40.07	60.73	61.12
T_9	41.58	55.66	55.59
SEm (±)	2.47	1.74	1.83
CD (0.05)	NS	NS	NS

NS- not significant

Table 7. Effect of seed invigouration treatments on number of branches and green leaves per plant of grain cowpea

Treatments	Number of branches per plant			Number of green leaves per plant	
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS
T_1	2.60	3.33	3.27	9.87	16.47
T_2	3.20	3.33	3.33	10.33	16.20
T_3	3.27	3.40	3.47	11.33	18.13
T_4	3.33	3.40	3.53	13.27	19.27
T_5	3.13	3.13	3.33	10.33	15.67
T_6	3.00	3.13	3.27	10.40	16.33
T_7	3.33	3.60	3.67	11.20	17.73
T_8	3.13	3.13	3.27	10.27	17.60
T_9	2.27	2.80	2.90	7.73	14.87
SEm (±)	0.19	0.12	0.11	0.62	0.60
CD (0.05)	0.587	0.374	0.320	1.886	1.816

Results revealed that, at 30 DAS, seeds primed in 0.025 percent $ZnSO_4$ for 4 h+ *Trichoderma viride* seed treatment 10 g kg^{-1} seed (T_7) recorded significantly higher DMP per plant (8.29 g) and it was statistically on par with T_5 (seeds pelleted with borax 50 mg kg^{-1} seed + *Trichoderma viride* seed treatment 10 g kg^{-1} seed), T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h) and T_2 (seeds pelleted with borax 100 mg kg^{-1} seed).

However, at 60 DAS T_1 (seeds pelleted with borax 50 mg kg^{-1} seed) recorded the highest DMP per plant (20.49 g), which was statistically on a line with T_2, T_4 and T_6 (T_2 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed)

At harvest stage, the highest DMP per plant (43.44 g) was registered in T_4 and it was comparable with T_1, T_2, T_6 and T_3 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h).

The control treatment registered the lowest DMP at all the three stages of observation.

4.2.3 Physiological Parameters

4.2.3.1 Leaf Area Index

Data pertaining to the effect of seed invigouration treatments on leaf area index at 30 DAS and 60 DAS are depicted in Table 9.

Leaf area index was markedly influenced by seed invigouration treatments both at 30 DAS and 60 DAS. Results revealed that at 30 DAS, seeds primed in $ZnSO_4$ 0.05 percent for 4 h (T_4) recorded the highest LAI (4.36) but it was statistically on par with T_1 and T_2 (seeds pelleted with borax 50 and 100 mg kg^{-1} seed), T_5 (T_1 + *Trichoderma viride* seed treatment10 g kg^{-1} seed) and T_3 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h).

However, at 60 DAS, T_3 recorded the highest LAI (5.99) among the treatments which was statistically comparable with T_5 and T_4.

Table 8. Effect of seed invigouration treatments on dry matter production of grain cowpea, g per plant

Treatment	Dry matter production		
	30 DAS	60 DAS	Harvest
T_1	5.84	20.49	43.27
T_2	6.87	20.21	39.73
T_3	6.63	18.40	39.33
T_4	7.29	19.95	43.44
T_5	8.10	16.60	30.07
T_6	5.47	18.88	39.33
T_7	8.29	16.99	28.20
T_8	6.35	14.80	27.47
T_9	5.18	13.12	26.93
SEm (±)	0.53	0.62	1.83
CD (0.05)	1.590	1.886	5.522

Table 9. Effect of seed invigouration treatments on LAI at 30 DAS and 60 DAS

Treatments	LAI 30 DAS	LAI 60 DAS
T_1	4.30	5.37
T_2	4.20	5.30
T_3	3.93	5.99
T_4	4.36	5.50
T_5	4.03	5.73
T_6	3.79	5.38
T_7	3.71	5.30
T_8	3.28	5.33
T_9	2.37	4.81
SEm (±)	0.17	0.18
CD (0.05)	0.514	0.547

71

Table 10. Effect of seed invigouration treatments on chlorophyll content of leaves at 30 DAS and 60 DAS, mg g^{-1}

Treatments	30 DAS			60 DAS		
	Chlorophyll a	Chlorophyll b	Total chlorophyll	Chlorophyll a	Chlorophyll b	Total chlorophyll
T_1	2.19	2.67	4.86	1.98	2.04	4.03
T_2	1.80	2.74	4.53	1.81	2.41	4.22
T_3	2.13	2.86	4.99	2.39	2.57	4.96
T_4	2.23	2.88	5.11	2.34	2.42	4.76
T_5	1.51	1.96	3.48	1.74	1.44	3.19
T_6	1.91	2.29	4.19	1.74	2.13	3.88
T_7	1.74	1.89	3.63	1.70	1.99	3.69
T_8	1.70	1.91	3.61	1.52	1.57	3.09
T_9	1.06	1.09	2.15	1.33	1.45	2.77
SE m (±)	0.07	0.16	0.18	0.10	0.16	0.16
CD (0.05)	0.209	0.490	0.528	0.314	0.493	0.481

72

The control treatment (T_9) registered significantly lower LAI at 30 DAS (2.37) and 60 DAS (4.81), respectively.

4.2.3.2 Chlorophyll Content

Data related to total chlorophyll, chlorophyll a and b content of leaves are presented in Table 10.

4.2.3.2.1 Total Chlorophyll Content

Total chlorophyll content of leaves was favourably influenced by seed invigouration treatments. At 30 DAS, T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h) recorded significantly higher total chlorophyll content in leaves (5.11 mg g^{-1}) but it was statistically on par with T_3 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h) and T_1 (seeds pelleted with 50 borax mg kg^{-1} seed). Control treatment (T_9) recorded significantly lower total chlorophyll content.

At 60 DAS also, total chlorophyll content of leaves was significantly influenced by seed invigouration treatments. Except T_7 (T_3 + *Trichoderma viride* seed treatment10 g kg^{-1} seed) and T_9 (control), all other treatments recorded lower chlorophyll content compared to 30 DAS. Among the treatments, the highest total chlorophyll content (4.96 mg g^{-1}) was observed in T_3 and it was statistically on par with with T_4. The control treatment (T_9) recorded the lowest total chlorophyll content (2.77 mg g^{-1}) and was on a line with T_5 (seeds pelleted with borax 50 mg kg^{-1} soil+ *Trichoderma viride* seed treatment 10g kg^{-1} seed) and T_8 (T_4 + *Trichoderma viride* seed treatment 10g kg^{-1} seed).

4.2.3.2.2 Chlorophyll a Content

The effect of seed invigouration treatments on chlorophyll a content at 30 and 60 DAS is shown in Table 10.

At 30 DAS, seed invigouration treatments significantly influenced the chlorophyll a content. The treatment, T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h) recorded significantly higher chlorophyll a content (2.23 mg g^{-1}) and was statistically comparable with T_1 (seeds pelleted with borax 50 mg kg $seed^{-1}$) and T_3

(seeds primed in $ZnSO_4$ 0.025 percent for 4 h). The lowest value was recorded in control treatment (1.06 mg g^{-1}).

Similarly, at 60 DAS also, chlorophyll a content was found significant. Among the treatments, T_3 recorded the highest chlorophyll a content (2.39 m g^{-1}), which was comparable with T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h). Similar to that at 30 DAS, control recorded the lowest chlorophyll a content and was statistically on par with T_8 (T_4 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed).

4.2.3.2.3 Chlorophyll b Content

Chlorophyll b content was also significantly influenced by seed invigouration methods at 30 DAS and 60 DAS (Table 10).

At 30 DAS, the highest chlorophyll b content (2.88 mg g^{-1}) was registered in the treatment T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h) and was statistically on par with T_3 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h), T_2 (seeds pelleted with borax 100 mg kg^{-1} seed) and T_1 (seeds pelleted with borax 50 mg kg^{-1} seed). The control (T_9) recorded significantly lower chlorophyll b content (1.09) among the treatments.

At 60 DAS, significantly higher chlorophyll b content (2.57 mg g^{-1}) was recorded in the treatment T_3 and was comparable with T_2, T_3 and T_6 (T_2 + *Trichoderma viride* seed treatment 10g kg^{-1} seed). The treatment, T_5 (T_1 + *Trichoderma viride* seed treatment 10g kg^{-1} seed) recorded the lowest chlorophyll b content (1.44 mg g^{-1}) and was on a line withT_8 (T_4 + *Trichoderma viride* seed treatment 10g kg^{-1} seed) and control (T_9).

4.2.3.3 Crop Growth Rate

Data regarding to the influence of seed invigouration treatments on crop growth rate from 30 DAS to 60 DAS and from 60 DAS to harvest stage are presented in Table 11.

Table 11. Effect of seed invigouration treatments on crop growth rate and relative growth rate of grain cowpea

Treatments	CGR (g m^{-2} day^{-1})		RGR (mg g^{-1} day^{-1})	
	30 DAS to 60 DAS	60 DAS to harvest	30 DAS to 60 DAS	60 DAS to harvest
T_1	11.46	16.81	45.22	24.92
T_2	9.83	14.47	35.95	22.41
T_3	8.97	15.51	34.01	25.21
T_4	9.28	17.37	33.67	25.82
T_5	6.60	9.98	24.16	19.81
T_6	10.53	15.15	41.23	24.43
T_7	6.34	8.30	24.53	17.24
T_8	5.69	9.28	28.56	20.52
T_9	6.07	10.18	31.37	24.11
SEm (±)	0.56	0.62	0.97	0.80
CD (0.05)	1.698	1.888	2.935	2.681

Seed invigouration treatments had significant effect on CGR at both stages of observation.

From 30 to 60 DAS, seeds pelleted with borax 50 mg kg^{-1} seed (T_1) recorded the highest CGR (11.46 g m^{-2} day^{-1}) and was statistically comparable with T_6 (T_2 + *Trichoderma viride* seed treatment 10g kg^{-1} seed (T_6) and T_2 (seeds pelleted with borax 100 mg kg^{-1} seed). The treatment T_8 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h + *Trichoderma viride* seed treatment 10g kg^{-1} seed) recorded the lowest CGR (5.69 g m^{-2} day^{-1}) and it was statistically comparable with T_7 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h + *Trichoderma viride* seed treatment 10g kg^{-1} seed), T_5 (T_1+ *Trichoderma viride* seed treatment 10g kg^{-1} seed) and T_9 (control).

Similarly, from 60 DAS to harvest stage, T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h) recorded the highest CGR (17.37 g m^{-2} day^{-1}) and it was statistically on a line with T_1 and T_3. The lowest CGR was observed in T_7 and it was statistically comparable with T_8, T_5 and T_9.

4.2.3.4 Relative Growth Rate

Data pertaining to the effect of seed invigouration treatments on RGR from 30 DAS to 60 DAS and from 60 DAS to harvest stage are presented in Table 11. Seed invigouration treatments favourably influenced the RGR at both the stages of observation.

Results on RGR from 30 DAS to 60 DAS revealed that the treatment, T_1 (seeds pelleted with borax 50 mg kg^{-1} seed) recorded significantly higher RGR (45.22 mg g^{-1} day^{-1}). The treatment T_1 was followed by T_6 (T_2 + *Trichoderma viride* seed treatment 10g kg^{-1} seed). The lowest RGR was recorded by T_7 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h + *Trichoderma viride* seed treatment 10g kg^{-1} seed) and was comparable with T_5 (T_1 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed).

From 60 DAS to harvest stage, T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h) recorded the highest RGR (25.82 mg g^{-1} day^{-1}) which was statistically on a line with T_3 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h), T_1 (seeds pelleted with borax

50 mg kg^{-1} seed), T_6 and T_9 (control). The treatment T_7 recorded the lowest RGR (17.24 mg g^{-1} day^{-1}) and was statistically on par with T_5 (T_1 + *Trichoderma viride* seed treatment 10g kg^{-1} seed).

4.2.4 Nodule Parameters

Results on nodule parameters *viz.*, total nodules per plant, effective nodules per plant, nodule fresh weight and nodule dry weight are presented in Table 12.

4.2.4.1 Total Nodules Per Plant

Seed invigouration methods had significant effect on total number of nodules per plant (Table 12). Seeds pelleted with borax 50 and 100 mg kg^{-1} seed (T_1 and T_2) recorded the highest total number of nodules per plant (32.7) and it was statistically on par with T_6 (T_2 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed). Among the treatments, the control (T_9) recorded the lowest number of nodules per plant (12.00).

4.2.4.2 Effective Nodules Per Plant

Seed invigouration treatments significantly influenced the effective nodules per plant (Table 12). The highest number of effective nodules per plant (29.0) was recorded in the treatment T_2 (seeds pelleted with borax 100 mg kg^{-1} seed). It was statistically on par with T_1 (seeds pelleted with borax 50 mg kg^{-1}seed) and T_6 (T_2 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed). The control (T_9) recorded the lowest number of effective nodules per plant (8.00).

4.2.4.3 Fresh Weight of Nodules Per plant

Fresh weight of nodules per plant was significantly influenced by seed invigouration treatments. Seeds primed in $ZnSO_4$ 0.05 percent for 4 h (T_4) recorded nodules with the highest fresh weight (0.60 g) and it was significantly superior to other seed invigouration treatments. The treatment T_4 was followed by T_3 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h) and T_3 was statistically on par with T_8 (T_4 + *Trichoderma viride* seed treatment 10g kg^{-1} seed). Among the treatments, control (T_9) registered the lowest fresh weight of nodules per plant (0.15 g).

Table 12. Effect of seed invigouration treatments on nodule parameters of grain cowpea at 50 per cent flowering

Treatments	Total no. of nodules per plant	No. of effective nodules per plant	Nodule fresh weight (g per plant)	Nodule dry weight (g per plant)
T_1	32.7	27.3	0.33	0.06
T_2	32.7	29.0	0.43	0.08
T_3	20.3	17.0	0.45	0.08
T_4	25.3	22.3	0.60	0.09
T_5	18.0	14.7	0.22	0.03
T_6	29.7	26.0	0.25	0.06
T_7	17.3	15.7	0.29	0.04
T_8	22.7	20.0	0.33	0.05
T_9	12.0	8.0	0.15	0.03
SEm (±)	1.9	1.5	0.03	0.01
CD (0.05)	5.74	4.41	0.074	0.014

18

.2.4.4 *Dry Weight of Nodules Per Plant*

Seed invigouration treatments significantly influenced the nodule dry weight per plant (Table 12). Seeds primed in $ZnSO_4$ 0.05 percent for 4 h (T_4) recorded the highest dry weight (0. 09 g) and it was statistically on par with T_3 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h) and T_2 (seeds pelleted with borax 100 mg kg^{-1} seed). The control (T_9) recorded the lowest dry weight of nodules (0.03 g).

4.2.5 Yield Parameters

The influence of seed invigoration treatments on yield attributes of grain cowpea are presented in Table 13.

4.2.5.1 Days to 50 Percent Flowering

Seed invigouration treatments did not have any significant effect on days to 50 percent flowering (Table 13). Though it was not significant T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h) recorded lesser days (41) to 50 percent flowering.

4.2.5.2 Pods Per Plant

Seeds primed in $ZnSO_4$ 0.05 percent for 4 h (T_4) recorded the highest no. of pods per plant (24.13) which was significantly higher to other treatments (Table 13). The treatment T_4 was followed by T_2 (seed pelleted with borax 100 mg kg^{-1} seed) which was comparable with T_3 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h), T_1 (seed pelleted with borax 100 mg kg^{-1} seed) and T_6 (T_1 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed). The control (T_9) recorded the lowest no. of pods per plant (11.06).

4.2.5.3 Seeds Per Pod

Seeds per pod was not significantly influenced by seed invigouration treatments (Table 13).

4.2.5.4 Pod Length

Differences in the length of pods due to seed invigouration treatments are depicted in Table 13. Among the treatments, seeds primed in $ZnSO_4$ 0.05 percent for 4 h (T_4) recorded the highest pod length (17.47 cm) and it was statistically on par with T_3 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h), T_6 (seed pelleted with borax 50 mg kg^{-1} seed + *Trichoderma viride* seed treatment 10g kg^{-1} seed), T_1 and T_2 (seeds pelleted with borax 50 and 100 mg kg^{-1} seed). The shortest pods were observed in the control treatment (14.99 cm).

4.2.5.5 Pod Girth

Results in Table 13 revealed that pod girth was significantly influenced by seed invigouration treatments. Among the treatments, seeds primed in $ZnSO_4$ 0.05 percent for 4 h (T_4) recorded the highest pod girth (2.00 cm) which was statistically on par with T_1 , T_2 (seed pelleted with borax 50 and 100 mg kg^{-1} seed), T_3 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h) and T_8 (T_4 + *Trichoderma viride* seed treatment 10g kg^{-1} seed. The lowest pod girth was observed in control (1.39 cm).

4.2.5.6 Pod Weight Per Plant

Pod weight was significantly influenced by seed invigouration treatments (Table 13). Seeds primed in $ZnSO_4$ 0.05 percent for 4 h (T_4) recorded the highest pod weight (17.05 g) and it was statistically comparable with T_1 (seeds pelleted with borax 50 mg kg^{-1} seed), T_3 (seed primed with $ZnSO_4$ 0.025 percent for 4 h), T_2 (seeds pelleted with borax 100 mg kg^{-1} seed) and T_6 (T_2+ *Trichoderma viride* seed treatment 10g kg^{-1} seed). The control (T_9) recorded the lowest pod weight (9.34 g).

4.2.5.7 100 Seed Weight

Seed invigouration treatments did not have any significant effect on hundred seed weight (Table 13).

4.2.6 Yield and Harvest Index

Results relating to the effect of seed invigouration treatments on seed yield per plant, seed yield ha^{-1}, haulm yield per plant, haulm yield ha^{-1} and harvest index are presented in Table 14.

4.2.6.1 Seed Yield Per Plant

Seed invigouration treatments had a significant effect on seed yield per plant. Seeds primed in $ZnSO_4$ 0.05 percent for 4 h (T_4) recorded the highest seed yield per plant (14.60 g) which was statistically on par with T_3 (seeds primed in $ZnSO_4$ 0.025 percent), T_1 and T_2 (seeds pelleted with borax 50 and 100 mg kg^{-1} seed) and T_6 (T_2 + *Trichoderma viride* seed treatment 10g kg^{-1} seed). The control (T_9) recorded the lowest seed yield per plant (6.93 g) and it was statistically comparable with T_7 and T_8 (seeds primed in $ZnSO_4$ 0.025 and 0.05 percent + *Trichoderma viride* seed treatment 10 g kg^{-1} seed).

4.2.6.2 Seed Yield Per Hectare

Seed yield ha^{-1} was favourably influenced by seed invigouration (Table 14) and the results followed the similar trend as that of seed yield per plant. The highest seed yield ha^{-1} (1446 kg ha^{-1}) was registered in T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h) and it was statistically on par with T_3 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h), T_1 and T_2 (seeds pelleted with borax 50 and 100 mg kg^{-1} seed) and T_6 (seeds pelleted with borax100 mg kg^{-1} seed + *Trichoderma viride* seed treatment 10g kg^{-1} seed). The lowest seed yield (842 kg ha^{-1}) was recorded by the control (T_9) and it was statistically comparable with T_8 (T_4 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed).

4.2.6.3 Haulm Yield Per Plant

Seed invigouration treatments had significant effect on haulm yield per plant (Table 14). Seeds primed in $ZnSO_4$ 0.05 percent for 4 h (T_4) recorded the highest haulm yield per plant (26.35 g) and it was statistically comparable with T_1 (seeds pelleted with borax 50 kg^{-1} seed), T_6 (T_2 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed), T_2 (seeds pelleted with borax 100 kg^{-1} seed) andT_3 (seeds primed in $ZnSO_4$ 0 0.025 percent for 4 h). The control (T_9) recorded lower haulm yield per plant (16.61 g) but was on par with T_5 (T_1 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed), T_7 (T_3 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed).

Table 13. Effect of seed invigouration treatments on yield attributes of grain cowpea

Treatments	Days to 50 per cent flowering	No. of pods per plant	No. of seeds per pod	Pod length (cm)	Pod girth (cm)	Pod weight (g per plant)	100 seed weight (g)
T_1	42.33	18.40	15.23	16.64	1.87	16.98	11.45
T_2	41.67	20.53	15.13	16.57	1.93	15.97	10.96
T_3	42.33	20.47	15.87	16.90	1.84	16.31	11.91
T_4	41.00	24.13	16.10	17.47	2.00	17.05	11.73
T_5	42.33	18.00	14.83	16.19	1.79	12.28	10.78
T_6	42.33	18.07	15.40	16.80	1.83	15.32	11.20
T_7	43.00	16.87	15.20	15.93	1.82	11.58	10.52
T_8	42.33	15.47	14.67	16.42	1.85	10.16	10.90
T_9	44.00	11.06	14.43	14.99	1.39	9.34	10.18
SE m (±)	1.50	1.54	0.49	0.31	0.05	0.89	0.63
CD (0.05)	NS	4.640	NS	0.940	0.165	2.667	NS

NS: not significant

Table 14. Effect of seed invigouration treatments on yield and harvest index of grain cowpea

Treatments	Seed yield per plant (g)	Haulm yield per plant (g)	Seed yield (kg ha^{-1})	Haulm yield (kg ha^{-1})	Harvest index
T_1	13.06	26.28	1246	3837	0.26
T_2	12.80	23.76	1234	3846	0.24
T_3	13.60	23.02	1250	3611	0.26
T_4	14.60	26.35	1446	3876	0.27
T_5	9.73	17.78	1100	3504	0.24
T_6	12.67	24.01	1213	3628	0.25
T_7	8.20	17.60	1094	3315	0.25
T_8	7.47	17.17	1063	3413	0.24
T_9	6.93	16.61	842	3178	0.21
SEm (±)	0.78	1.43	78	92	0.01
CD (0.05)	2.369	4.331	235.6	277	0.030

4.2.6.4 Haulm Yield Per Hectare

Seed invigouration treatments also had significant effect on the haulm yield ha^{-1} of grain cowpea (Table 14). The results of haulm yield ha^{-1} followed the similar trend as that of haulm yield per plant. Seeds primed in $ZnSO_4$ 0.05 percent for 4 h (T_4) recorded the highest haulm yield (3876 kg ha^{-1}) among the treatments and it was statistically comparable with T_1 and T_2 (seeds pelleted with borax 50 and 100 mg kg^{-1} seed), T_6 (T_2 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed) and T_3 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h). The control recorded the lowest haulm yield per ha (3178 kg ha^{-1}) but was statistically on a line with T_7 (T_3 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed) and T_8 (T_4 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed).

4.2.6.5 Harvest Index

The treatment T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h) recorded higher HI (0.27) (Table 14) and it was statistically on par with T_1 and T_2 (seeds pelleted with borax 50 and 100 mg kg^{-1} seed), T_3 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h), T_6 (T_2+ *Trichoderma viride* seed treatment 10 g kg^{-1} seed), and T_7 (T_3 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed). The control treatment registered the lowest harvest index (0.21) but it was on par with T_5 (T_1 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed) and T_8 (T_4 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed).

2.7 Quality Parameter

4.2.7.1 Crude Protein Content of Seed

The influence of seed invigouration treatments on crude protein content of the seed is furnished in Table 15.

Results revealed that seed invigouration treatments had significant effect on the crude protein content of seed. Among the treatments, T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h) recorded significantly higher crude protein content (27.11 percent) which was statistically comparable with all seed invigouration treatments except T_8 (T_4 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed). Crude protein content of seed was the lowest in control (T_9).

4.2.8 Nutrient Uptake by Crop

Uptake of N, P, K, Zn and B by the crop at harvest stage are presented in Table 16 to 20.

4.2.8.1 N Uptake by Crop

The results presented in Table 16 indicated that seed invigouration treatments significantly influenced the total N uptake by the crop. Seeds primed in $ZnSO_4$ 0.05 percent for 4 h (T_4) recorded the highest N uptake by grain cowpea (96.38 kg ha^{-1}) which was statistically comparable with T_1 (seeds pelleted with borax 50 and 100 mg kg $seed^{-1}$), T_3 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h) and T_6 (seeds pelleted with borax 100 mg kg $seed^{-1}$ + *Trichoderma viride* seed treatment 10g kg^{-1}). The lowest total N uptake (51.31 kg ha^{-1}) by the crop was registered in T_9 (control).

The N uptake by haulm was also found significant. Among the treatments, the highest N uptake (51.64 kg ha^{-1}) by haulm was registered in T_7 (T_3 + *Trichoderma viride* seed treatment 10g kg^{-1} seed) and it was on a line with T_4, T_6, T_5 (T_1 + *Trichoderma viride* seed treatment 10g kg^{-1} seed), T_1, T_2 and T_3 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h). The control treatment recorded the lowest N uptake by haulm (32.83 kg ha^{-1}).

Table 15. Effect of seed invigouration treatments on crude protein content of seed

Treatments	Crude protein content (%)
T_1 -Seed pelleting with borax 50 mg kg^{-1} seed	26.50
T_2 -Seed pelleting with borax 100 mg kg^{-1} seed	26.25
T_3 -Seed priming with $ZnSO_4$ 0.025 per cent for 4 h	26.25
T_4 -Seed priming with $ZnSO_4$ 0.05 per cent for 4 h	27.11
T_5-Seed pelleting with borax 50 mg kg^{-1} seed + *Trichoderma viride* seed treatment10 g kg^{-1} seed	25.25
T_6-Seed pelleting with borax 100 mg kg^{-1} seed + *Trichoderma viride* seed treatment 10 g kg^{-1} seed	25.81
T_7 -Seed priming with $ZnSO_4$ 0.025 per cent for 4h + *Trichoderma viride* seed treatment 10 g kg^{-1} seed	25.38
T_8-Seed priming with $ZnSO_4$ 0.05 per cent for 4h + *Trichoderma viride* seed treatment10 g kg^{-1} seed	23.63
T_9 -Control	21.00
SEm (±)	0.74
CD (0.05)	2.231

Seed invigouration treatments also significantly influenced the N uptake by seed. The treatment T_4 recorded the highest N uptake by grain (46.96 kg ha^{-1}) which was statistically on par with T_1, T_2, T_3 and T_6. The lowest N uptake by seed was recorded in control (18.48 kg ha^{-1}).

4.2.8.2 P Uptake

Seed invigouration treatments significantly influenced the total P uptake by the crop (Table 17). Seeds primed in $ZnSO_4$ 0.05 percent for 4 h (T_4) recorded the highest total P uptake by crop (35.56 kg ha^{-1}) and it was statistically comparable with T_2 (seeds pelleted with borax 100 mg kg^{-1} seed). The treatment T_2 was comparable with T_3 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h) and T_6 (T_2 + *Trichoderma viride* seed treatment 10g kg^{-1} seed). The control (T_9) recorded the lowest total P uptake (14.69 kg ha^{-1}) and was significantly inferior to other treatments.

Seed invigouration treatments also significantly influenced the P uptake by haulm. The highest P uptake by haulm (17.02 kg ha^{-1}) was observed in T_2 and it was followed by T_7 (T_3+ *Trichoderma viride* seed treatment 10g kg^{-1} seed). The treatment T_7 was statistically comparable with T_4 and T_3. The control (T_9) recorded significantly lower P uptake by haulm (8.61 kg ha^{-1}).

Phosphorus uptake by seed was also found significant. Among the treatments, the highest P uptake by seed (20.83 kg ha^{-1}) was observed in the treatment T_4 and it was followed by T_6. The treatment T_6 was statistically on par with T_2, T_3 and T_1 (seeds pelleted with borax 50 mg kg^{-1} seed). Among the treatments, the control recorded the lowest P uptake by seed (6.41 kg ha^{-1}).

4.2.8.3 K Uptake

Seed invigouration treatments significantly influenced the total K uptake by crop (Table 18). The treatment, T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h) recorded the highest total K uptake (63.70 kg ha^{-1}), which was comparable with T_3 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h), T_1 and T_2 (seeds pelleted with borax 50 and 100 mg kg^{-1} seed) and T_6 (seeds pelleted with borax 100 mg kg $seed^{-1}$ +

Trichoderma viride seed treatment 10g kg^{-1} seed). The control (T_9) recorded the lowest total K uptake by crop (33.41 kg ha^{-1}).

Potassium uptake by haulm was also significantly influenced by seed invigouration treatments. Seeds primed in $ZnSO_4$ 0.05 percent for 4 h (T_4) recorded higher K uptake by haulm (31.17 kg ha^{-1}) and was statistically comparable with T_1 and T_2, T_3 T_5 (T_1 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed), T_6 and T_8 (T_4 + *Trichoderma viride* seed treatment 10g kg^{-1} seed). The control treatment recorded significantly lower value (16.47 kg ha^{-1}).

Seed invigouration treatments also markedly influenced the K uptake by seed. The treatment T_1 recorded the highest K uptake by seed (32.96 kg ha^{-1}) which was statistically comparable with T_2, T_3, T_4 and T_6. The control registered the lowest K uptake by seed (16.94 kg ha^{-1}).

4.2.8.4 Zn Uptake

Seed invigouration treatments had a significant effect on total Zn uptake by crop (Table 19). The treatment, T_8 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h + *Trichoderma viride* seed treatment 10g kg^{-1} seed) recorded the highest total Zn uptake by crop which was statistically comparable with all treatments except T_5 (seeds pelleted with borax 50 mg kg^{-1} seed + *Trichoderma viride* seed treatment 10g kg^{-1} seed), T_2 (seeds pelleted with borax 100 mg kg^{-1} seed) and control (T_9).

Zn uptake by haulm was also significantly influenced by seed invigouration treatments. The treatment T_8 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h + *Trichoderma viride* seed treatment 10g kg^{-1} seed) registered the highest Zn uptake by haulm which was statistically comparable with all seed invigouration treatments except control. The control registered the lowest Zn uptake by haulm (0.186 kg ha^{-1}).

The highest Zn uptake by seed was recorded in T_4 (seeds primed in 0.05 percent $ZnSO_4$ for 4 h) and it was statistically comparable with T_3 (seeds primed with 0.025 percent $ZnSO_4$ for 4 h), T_7 (T_3+ *Trichoderma viride* seed treatment 10g

kg^{-1} seed) and T_8 (T_4+ *Trichoderma viride* seed treatment 10g kg^{-1} seed). The control treatment registered the lowest Zn uptake by seed (0.061kg ha^{-1}).

4.2.8.5 B Uptake

Seed invigouration treatments significantly influenced the total B uptake by grain cowpea (Table 20). Among the treatments, T_2 (seeds pelleted with borax 100 mg kg^{-1} soil) registered higher total B uptake by crop and it was statistically on par with all treatments except T_7 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h + *Trichoderma viride* seed treatment 10 g kg^{-1} seed) and the lowest total B uptake by crop (0.298 kg ha^{-1}) was registered in control.

Seed invigouration treatment also had a significant effect on B uptake by haulm. The treatment T_2 registered the highest B uptake by haulm which was statistically comparable with T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h), T_6 (T_2 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed) and T_7. The lowest B uptake by haulm was recorded in control (T_9) (0.239 kg ha^{-1}).

Boron uptake by seed was also favourably influenced by seed invigouration treatments. The treatment T_8 recorded the highest uptake of B by seed (0.112 g ha^{-1}) which was comparable with T_4 and T_3 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h).

Table 16. Effect of seed invigouration treatments on N uptake by crop at harvest, kg ha^{-1}

Treatment	N uptake		
	Uptake by haulm	Uptake by seed	Total uptake
T_1	46.69	45.40	92.10
T_2	43.37	43.70	87.07
T_3	44.31	43.94	88.25
T_4	49.43	46.96	96.38
T_5	47.49	32.50	79.99
T_6	47.81	40.42	88.23
T_7	51.64	32.76	84.40
T_8	40.88	25.57	66.45
T_9	32.83	18.48	51.31
SEm (±)	3.23	3.07	3.41
CD (0.05)	9.763	9.271	10.321

Table 17. Effect of seed invigouration treatments on P uptake by crop at harvest, kg ha^{-1}

Treatment	P uptake by crop		
	Uptake by haulm	Uptake by seed	Total uptake
T_1	13.48	15.10	28.59
T_2	17.02	15.79	32.82
T_3	14.88	15.64	30.53
T_4	14.73	20.83	35.56
T_5	11.84	10.99	22.83
T_6	12.38	17.28	29.66
T_7	15.33	10.87	26.20
T_8	12.85	8.47	21.32
T_9	8.28	6.41	14.69
SEm (±)	0.58	0.86	1.08
CD (0.05)	1.741	2.614	3.271

Table 18. Effect of seed invigouration treatments on K uptake by crop at harvest, kg ha^{-1}

Treatment	K uptake by crop		
	Uptake by haulm	Uptake by seed	Total uptake
T_1	29.56	32.96	62.52
T_2	30.58	29.74	60.32
T_3	30.35	32.43	62.78
T_4	31.17	32.53	63.70
T_5	28.67	23.18	51.85
T_6	29.48	28.74	58.22
T_7	24.68	19.74	44.41
T_8	30.68	18.45	45.60
T_9	16.47	16.94	33.41
SEm (±)	1.69	1.94	2.99
CD (0.05)	5.106	5.852	9.061

Table 19. Effect of seed invigouration treatments on Zn uptake by crop at harvest, kg ha^{-1}

Treatment	Zn uptake by crop		
	Uptake by haulm	Uptake by seed	Total uptake
T_1	0.217	0.088	0.305
T_2	0.217	0.077	0.294
T_3	0.221	0.090	0.310
T_4	0.213	0.102	0.315
T_5	0.206	0.082	0.289
T_6	0.221	0.087	0.308
T_7	0.216	0.094	0.310
T_8	0.236	0.093	0.329
T_9	0.186	0.061	0.246
SEm (±)	0.008	0.004	0.009
CD (0.05)	0.0248	0.0131	0.027

Table 20. Effect of seed invigouration treatments on B uptake by crop at harvest, kg ha^{-1}

Treatment	B uptake by crop		
	Uptake by haulm	Uptake by seed	Total uptake
T_1	0.285	0.079	0.364
T_2	0.346	0.073	0.419
T_3	0.279	0.097	0.376
T_4	0.307	0.104	0.410
T_5	0.282	0.078	0.360
T_6	0.301	0.088	0.389
T_7	0.215	0.083	0.298
T_8	0.245	0.112	0.356
T_9	0.239	0.059	0.298
SEm (±)	0.018	0.007	0.025
CD (0.05)	0.056	0.021	0.075

4.2.9 Disease Incidence

Seed invigouration had significant effect on anthracnose disease incidence in grain cowpea (Table 21). Anthracnose disease was the major disease observed when the crop was at 20 DAS. From the results, it was observed that, seed invigouration treatments registered lower incidence of anthracnose compared to control. The lowest percentage of incidence (20.7 percent) was observed in the treatment T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4h). It was followed by T_3 (seeds primed in $ZnSO_4$ 0.025 percent for 4h) and T_3 was statistically on a line with T_1 and T_2 (seeds pelleted with borax 50 and 100 mg kg^{-1} seed) and T_6 (T_1 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed). The highest percentage incidence was observed in control (33.9 percent).

4.2.10 Economics

The economics of cultivation in terms of net income and B: C ratio as influenced by seed invigouration treatments is presented in Table 22.

4.2.10.1 Net Income

Net Income was also significantly influenced by seed invigouration treatments as evident from Table 22. Results followed the similar trend as that of gross income. Among the treatments, T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h) recorded significantly higher net income ha^{-1} (₹ 55, 387 ha^{-1}). The lowest income was registered in T_9 (control) and was significantly different from other treatments.

4.2.10.2 B:C Ratio

Benefit cost ratio also followed the similar trend as that of gross and net income (Table 22). Seeds primed in $ZnSO_4$ 0.05 percent for 4 h (T_4) registered the highest B: C ratio (1. 92) and it was statistically comparable with T_3 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h), T_1 and T_2 (seeds pelleted with borax 50 and 100 mg kg^{-1} seed) and T_6 (T_2+ *Trichoderma viride* seed treatment 10 g kg^{-1} seed). The control treatment (T_9) registered the lowest B:C ratio (1.12).

Table 21. Effect of seed invigouration treatments on percentage disease index of anthracnose

Treatments	Percentage disease index	
T_1-Seed pelleting with borax 50 mg kg^{-1} seed	22.4	(28.22)
T_2-Seed pelleting with borax 100 mg kg^{-1} seed	22.7	(28.40)
T_3-Seed priming with $ZnSO_4$ 0.025 per cent for 4 h	21.7	(27.72)
T_4-Seed priming with $ZnSO_4$ 0.05 per cent for 4 h	20.7	(27.01)
T_5-Seed pelleting with borax 50 mg kg^{-1} seed + Trichoderma *viride* seed treatment10 g kg^{-1} seed	24.0	(29.32)
T_6-Seed pelleting with borax 100 mg kg^{-1} seed + *Trichoderma viride* seed treatment 10 g kg^{-1} seed	22.7	(28.42)
T_7-Seed priming with $ZnSO_4$ 0.025 per cent for 4h + *Trichoderma viride* seed treatment 10 g kg^{-1} seed	24.3	(29.54)
T_8-Seed priming with $ZnSO_4$ 0.05 per cent for 4h + *Trichoderma viride* seed treatment10 g kg^{-1} seed	24.0	(29.27)
T_9 -Control	33.9	(35.56)
SEm (±)		0.96
CD (0.05)		2.894

Values in parentheses are transformed values, (arc sine transformation)

Table 22. Effect of seed invigouration treatments on economics of cultivation

Treatments	Net income (₹ ha^{-1})	B: C ratio
T_1-Seed pelleting with borax 50 mg kg^{-1} seed	39282	1.65
T_2-Seed pelleting with borax 100 mg kg^{-1} seed	38170	1.63
T_3-Seed priming with $ZnSO_4$ 0.025 per cent for 4 h	39,721	1.66
T_4-Seed priming with $ZnSO_4$ 0.05 per cent for 4 h	55,387	1.92
T_5-Seed pelleting with borax 50 mg kg^{-1} seed + Trichoderma *viride* seed treatment10 g kg^{-1} seed	27,590	1.46
T_6-Seed pelleting with borax 100 mg kg^{-1} seed + *Trichoderma viride* seed treatment 10 g kg^{-1} seed	36,452	1.60
T_7-Seed priming with $ZnSO_4$ 0.025 per cent for 4h + *Trichoderma viride* seed treatment 10 g kg^{-1} seed	27, 223	1.45
T_8-Seed priming with $ZnSO_4$ 0.05 per cent for 4h + *Trichoderma viride* seed treatment10 g kg^{-1} seed	24,695	1.41
T_9 -Control	7, 385	1.12
SEm (±)	1, 259	0.10
CD (0.05)	3807.8	0.312

4.2.11 Soil Nutrient Status

The results on the effect of seed invigouration treatments on organic carbon content and available N, P, K, Zn and B status in the soil after the experiment are presented in Table 23 and 24.

4.2.9.11.1 Organic Carbon Content of Soil

The organic carbon content of soil was significantly influenced by seed invigouration treatments (Table 23). The highest organic carbon content of soil (1.018 percent) was observed in the treatment, treatment T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h) which was statistically comparable with T_1 (seeds pelleted with borax 50 mg kg^{-1} seed), T_3 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h), T_5 (T_1+ *Trichoderma viride* seed treatment 10 g kg^{-1} seed), T_7 (seeds primed in $ZnSO_4$ 0.025 percent for 4h +*Trichoderma viride* seed treatment 10 g kg^{-1} seed) and T_8 (T_4+*Trichoderma viride* seed treatment 10 g kg^{-1} seed). The control (T_9) recorded the lowest soil organic carbon content.

4.2.11.2 Available N Status

Seed invigouration treatments had profound influence on available N status of the soil (Table 23). Seeds primed in $ZnSO_4$ 0.05 percent for 4 h (T_4) recorded higher soil available N (376.31 kg ha^{-1}) which was statistically comparable with all seed invigouration treatments except T_2 (seeds pelleted with borax 100 mg kg^{-1} soil) and control (T_{13}).

4.2.11.3 Available P Status of Soil

The results depicted in Table 23 indicated that seed invigouration treatments significantly influenced the available P status of the soil. Seeds pelleted with borax 100 mg kg^{-1} soil (T_2) recorded the highest available soil P (48.63 kg ha^{-1}), which was on par with T_1 (seeds pelleted with borax 100 mg kg^{-1} soil). The lowest available P was recorded in the control (22.78 kg ha^{-1}).

Table 23. Effect of seed invigouration treatments on organic carbon and available N, P and K status of soil after the experiment

Treatments	Organic carbon (%)	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
T_1	0.920	363.78	41.89	117.39
T_2	0.976	338.69	48.63	125.77
T_3	0.977	363.78	37.95	135.41
T_4	1.018	376.31	35.70	131.60
T_5	0.883	319.27	38.37	128.50
T_6	0.864	329.59	38.51	127.23
T_7	0.852	329.78	29.09	149.14
T_8	0.896	338.69	27.64	146.37
T_9	0.663	313.59	22.78	98.73
SEm (±)	0.044	16.43	2.82	6.62
CD (0.05)	0.1317	49.679	8.515	20.006

4.2.9.4 Available K Status of Soil

The result furnished in Table 23 revealed that seed invigouration treatments favourably influenced the available K status of the soil. Among the treatments, higher soil available K (149.14 kg ha^{-1}) was registered in the treatment T_7 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h + *Trichoderma viride* seed treatment10 g kg^{-1} seed) and it was comparable with T_8 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h+ *Trichoderma viride* seed treatment 10 g kg^{-1} seed), T_3 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h), T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h), T_5 (seeds pelleted with borax 50 mg kg^{-1} soil + *Trichoderma viride* seed treatment10 g kg^{-1} seed) . The lowest soil available K status (98.73 kg ha^{-1}) was observed in control.

4.2.9.5 Available Zn Status

The available Zn status in the soil was significantly influenced by seed invigouration treatments (Table 24). The treatment T_8 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h + *Trichoderma viride* seed treatment 10 g kg^{-1} seed) registered the highest available Zn status (2.223 mg kg^{-1} soil) which was significantly different from other treatments. The treatment T_8 was followed by T_7 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h + *Trichoderma viride* seed treatment 10 g kg^{-1} seed) and T_4; T_4 was statistically comparable with T_1 (seeds pelleted with borax 50 mg kg^{-1} seed). The lowest available Zn status (0.403 mg kg^{-1} soil) was registered in control (T_9) and was significantly inferior to other treatments.

4.2.8.6 Available B Status of Soil

Seed invigouration treatments significantly influenced the available B status of soil (Table 24). The treatment T_2 (seeds pelleted with borax 100 mg kg^{-1} seed) registered the highest available B status which was significantly different from other treatments and it was followed by T_1 (seeds pelleted with borax 50 mg kg^{-1} seed). The control treatment (T_9) registered the lowest available B status.

Table 24. Effect of seed invigouration treatments on Zn and B content of soil after the experiment, mg kg^{-1} soil

Treatments	Available Zn content	Available B content
T_1	0.861	0.115
T_2	0.577	0.140
T_3	1.237	0.057
T_4	1.484	0.073
T_5	1.1996	0.088
T_6	0.808	0.088
T_7	1.912	0.051
T_8	2.223	0.080
T_9	0.403	0.021
SEm (±)	0.034	0.004
CD (0.05)	0.1033	0.012

Discussion

5. DISCUSSION

The results of the investigation entitled "Seed invigouration for yield enhancement in grain cowpea (*Vigna unguiculata* L. Walp)" conducted at Coconut Research Station, Balaramapuram, Thiruvananthapuram district, Kerala, are discussed in this chapter.

5.1 EXPERIMENT NO. I - POT CULTURE EXPERIMENT TO STUDY THE INFLUENCE OF SEED INVIGOURATION METHODS ON GERMINATION AND SEEDLING VIGOUR OF GRAIN COWPEA

5.1.1 Effect of Seed Invigouration Treatments on Germination Parameters

Seed invigouration treatments significantly influenced the seed germination parameters *viz*, GP, SG, GI, GRI, MGT and MDG. However, CRG and T_{50} were not significantly influenced by seed invigouration. Mean germination time was calculated to find out the mean time a seed took to initiate and end germination process. Germination index gave a measure of both the percentage and speed of germination while, GRI gave an indication of percentage seeds germinated per day of test period. Coefficient of rate of germination indicated the rapidity of germination. Among the treatments T_3 (seed pelleting with borax 50 mg kg^{-1} seed), T_4 (seed pelleting with borax 100 mg kg^{-1} seed), T_5 (seed pelleting with $ZnSO_4$ 100 mg + borax 50 mg kg^{-1}seed), T_7 (seed priming with $ZnSO_4$ 0.025 percent for 4 h) and T_8 (seed priming with $ZnSO_4$ 0.05 percent for 4 h) recorded higher SG, MDG, GI and GRI and less MGT. The enhancement in germination observed in T_3, T_4, T_5, T_7 and T_8 were in the order of 22.22, 20.38, 20.28, 20.38 and 18.51 percent, respectively over control. These treatments also recorded less MGT, higher values for MDG, GI and GRI compared to other treatments. Though it was not significant, the treatments T_3, T_4, T_5, T_7 and T_8 also recorded higher CRG and lesser T_{50}. Hussain *et al.* (2006) reported that seed invigouration treatments activate the metabolic process taking place during the phase I and II of germination process before the radicle emergence. This may lead to the acceleration of germination and resulting in high SG, MDG, GI, GRI and less MGT. Aboutalebian *et al.* (2012) observed that $ZnSO_4$ priming enhanced the speed of germination in wheat. Similarly, Chomontowski *et al.* (2019) re that seed priming resulted in higher speed of germination. Nutripriming with KCl reduced the mean germination time in cabbage (Batool *et al.*, 2015). Prakash *et al.* (2018) pointed out that seed pelleting may resulted in increased hydration of colloids and greater viscosity of plasma membrane and cell membrane which allows rapid entry of moisture into the seed. Rapid entry of moisture into the seed triggers the hydrolysis of reserved food material in the seed resulting in the growth of embryo which facilitates fast emergence compared to untreated seeds (Andoh and Kobata, 2002).

5.1.2 Effect of Seed Invigouration Treatments on Vigour Index and Seedling Growth

Seed invigouration treatments favourably influenced the growth parameters of seedlings *viz.*, shoot and root length, fresh and dry shoot weight, fresh and dry root weight, seedling vigour index I and II. Among the twelve seed invigouration treatments, treatments T_3 (seed pelleting with borax 50 mg kg^{-1} seed), T_4 (seed pelleting with borax 100 mg kg^{-1} seed), T_5 (seed pelleting with $ZnSO_4$ 100 mg + borax 50 mg kg^{-1}seed), T_7 (seed priming with $ZnSO_4$ 0.025 percent for 4 h) and T_8 (seed priming with $ZnSO_4$ 0.05 percent for 4 h) recorded higher root and shoot length, higher dry matter production and higher vigour index. Improvement in seedling growth observed in T_3, T_4, T_5, T_7 and T_8 might be due to the fact that pre-germination process *viz.*, membrane repair, DNA and RNA synthesis and repair, embryo development, modifications of endosperm tissue surrounding the embryo, reserve mobilization *etc.* has been favourably initiated in these treatments prior to sowing. Heydeckar and Cool bear (1977) reported that in primed seeds, radicle protrusion occurs in a very fast manner, since the pre-germinative process have already been completed. Rowse (1995) also opined that primed seeds rapidly imbibe water and revive seed metabolism resulting in a fast and uniform emergence of seedling with good vigour. Compared to control, the treatments T_3, T_4, T_5, T_7 and T_8 produced seedlings with 41.69 to 48.87 percent more seedling vigour index I and

Plate 3. Performance of best pelleting treatments (T_3 and T_4)

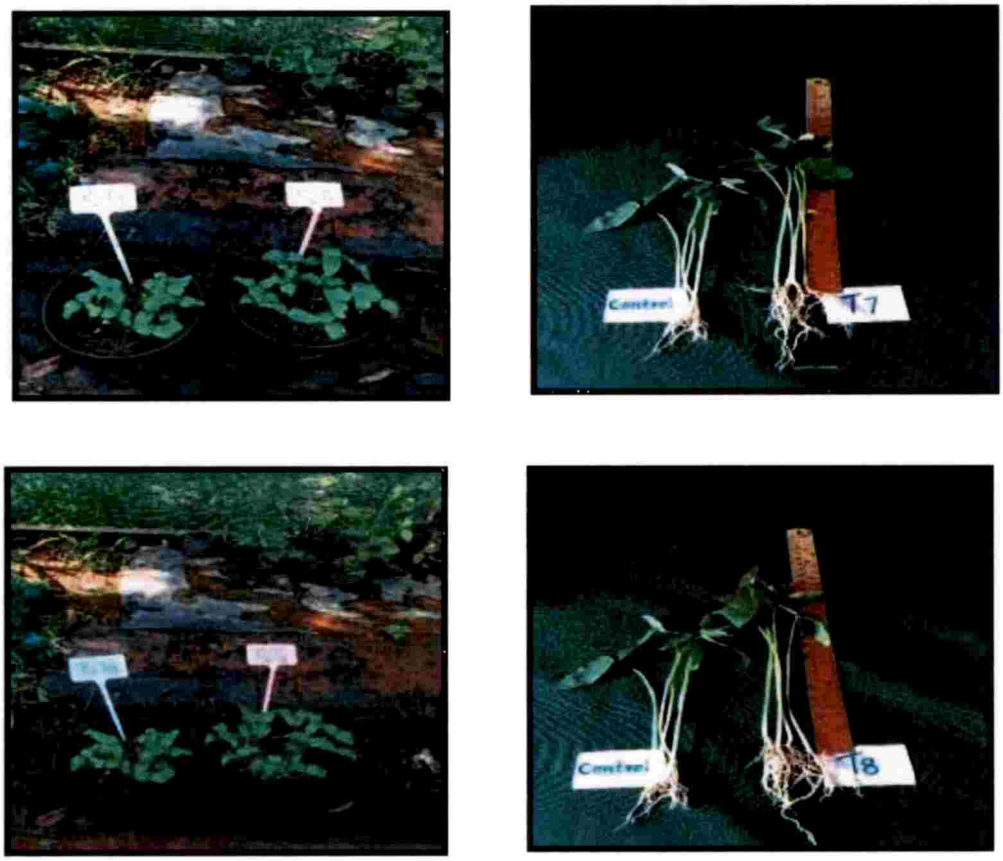


Plate 4. Performance of best priming treatments (T_7 and T_8)

63.84 to 81.75 percent more vigour index II. Higher seedling vigour index I and II observed in these treatments might be due to the better seedling length and biomass recorded in these treatments (Table 3). Improved seedling growth and biomass production observed in these treatments might be due to increased metabolic activity, earliness in germination and seedling growth as observed from the data on SG, MGT, T_{50}, GI, GRI and seedling growth. The improvement in seedling growth due to $ZnSO_4$ and borax pelleting was also observed by Masuthi *et al.* (2009). Carrot seeds primed in one percent $ZnSO_4$ solution recorded higher germination percentage, mean root and shoot length and vigour index (Munawar *et al.*, 2013). Similarly, Ajouri *et al.* (2004) reported that seed priming with Zn improved the germination and seedling development in barley. The beneficial effect of seed pre-treatment in germination and dry weight of seedling was also reported by Abdulrahmani *et al.* (2007) and Ghassemi-Golezai *et al.* (2008).

5.2. EXPERIMENT NO. II -FIELD EXPERIMENT TO STUDY THE EFFECT OF SEED INVIGOURATION TECHNIQUES ON YIELD ENHANCEMENT IN GRAIN COWPEA

5.2.1 Seed Invigouration Treatments on Field Emergence

Seed invigouration significantly influenced the final germination percentage of grain cowpea compared to control. Due to seed invigouration, an enhancement in the final emergence of 20.54 to 27.79 percentage was observed. Though, the treatment T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h) recorded the highest germination percentage (97.86 percent), it was statistically comparable with all the seed invigouration treatments. Osmotic adjustment, metabolic process repair and build-up of metabolites occurred during seed invigouration may be the plausible reason for higher germination in seed invigouration treatments (Chen and Arora, 2013; Jisha *et al.*, 2013). Seed invigouration shortened or reduced the lag or metabolic phase in the germination process. In normal course, metabolic or lag phase in the germination process occurs when the seeds are fully imbibed or just before the radicle emergence. During seed invigouration, the seeds have already completed the lag phase or metabolic phase and hence germination time in the field has been reduced resulting in the fast and uniform emergence of seedlings with better establishment and higher germination percentage. The result is in consonance with the observations made by Basra *et al.* (2005) and Ghiyasi *et al.* (2008) who observed that seed invigouration improved the germination and establishment. Thomson and El-Kassaby (1993) viewed that faster the seed germination, better the chance of survival in the field. The lesser percentage of emergence observed in the control might be due to seed damage by soil borne pathogens or pests or due to low vigour of seeds.

5.2.2 Seed Invigouration Treatments on Growth Parameters

Seed invigouration treatments significantly influenced the growth parameters *viz*., number of green leaves per plant (30 DAS and 60 DAS), number of branches per plant and dry matter production (30 DAS, 60 DAS and harvest stage). Results revealed that plant height increased with the progress of crop growth, though it was not significantly influenced by seed invigouration treatments.

In general, seed invigouration treatments recorded higher number of branches per plant than control. Chaubey *et al.* (1999) and Vaiyapuri *et al.* (2010) also made similar observations that seeds pelleted with Zn and B enhanced the primary branches in lentil and soybean. At 60 DAS and harvest stage, seeds primed in $ZnSO_4$ recorded higher number of branches than borax pelleted seeds. This might be due to the fact that Zn plays a major role in the biosynthesis of tryptophan which is the precursor of plant hormone IAA and IAA helps to trigger the growth of the plant tissues (Naruka *et al.*, 2000). Usman *et al.* (2014) reported that seed treatment with $ZnSO_4$ significantly increased the pod bearing branches in green gram. The highest number of branches were recorded in T_7 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h + *Trichoderma viride* seed treatment 10 g kg^{-1} seed) at 30 DAS, 60 DAS and at harvest, this might be due to production of plant growth hormones especially IAA by *Trichoderma viride* (Chagas *et al.*, 2016).

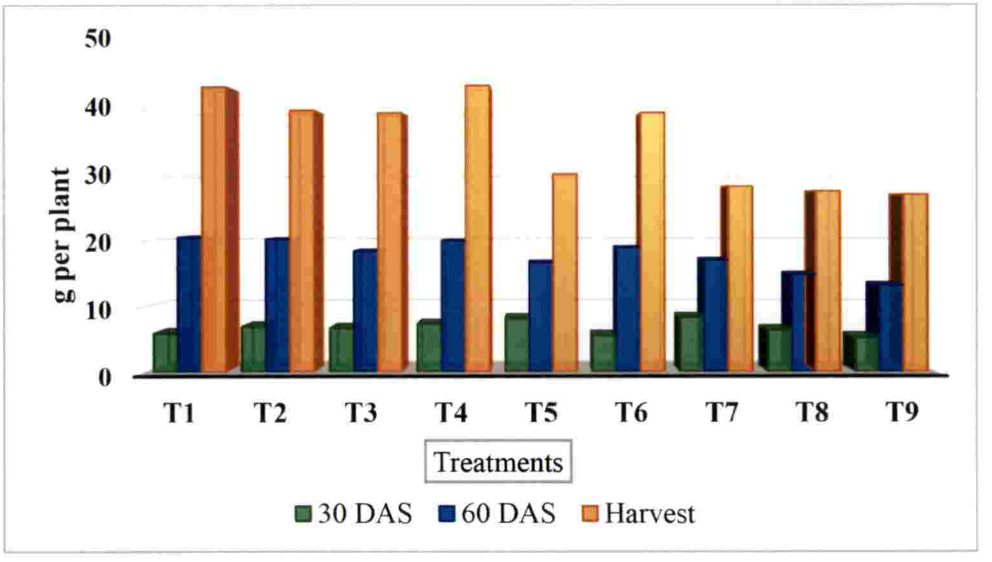


Fig. 3 Effect of seed invigouration treatments on DMP at 30 DAS, 60 DAS and harvest, g per plant

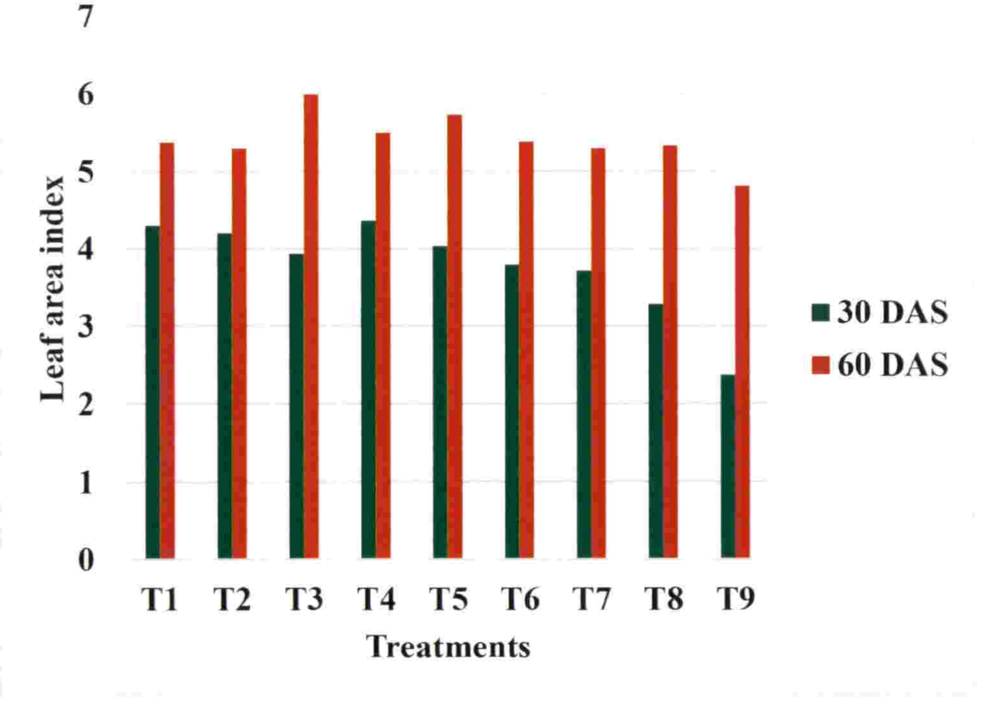


Fig. 4 Effect of seed invigouration treatments on leaf area index at 30 DAS and 60 DAS

Seed invigouration treatments had significant effect on green leaves per plant at 30 DAS and 60 DAS. Compared to control, seeds pelleted with borax and primed in $ZnSO_4$ recorded higher number of green leaves per plant at both stages of observation. Seed invigouration resulted in fast and uniform emergence of vigourous seedlings, which paved the way for increased crop growth. At 30 DAS and 60 DAS, the highest number of green leaves were observed in the treatment T_5 (seeds pelleted with borax 50 mg kg^{-1} seed + *Trichoderma viride* seed treatment 10 g kg^{-1} seed). However, at 60 DAS, though the treatment T_5 recorded the highest number of leaves it was statistically on par with T_3 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h), T_7 and T_8 (seeds primed in $ZnSO_4$ 0.025 and 0.05 percent for 4 h followed by *Trichoderma viride* seed treatment 10 g kg^{-1} seed). Masuthi (2005) revealed that cowpea seeds pelleted with $ZnSO_4$ increased the number of leaves compared to control. Rehman *et al.* (2012) observed that in rice, the number and rate of leaf and tiller production were considerably increased by seed priming with lower concentration of B solution.

Seed invigouration treatments significantly influenced the dry matter production. As the crop advances its age the DMP was found to increase. The maximum DMP of grain cowpea was observed at harvest stage. Higher DMP per unit area is necessary for higher production, which in turn depends on assimilating leaf area and environmental conditions (Reshma, 2014). Compared to control, seed invigoration treatments recorded higher DMP at all the stages of observation. Better DMP recorded in these treatments was due to the production of more branches and leaves (Table 7) which will enhance the assimilatory area and photosynthesis. The treatment T_4 (seeds primed in $ZnSO_4$ percent for 4 h) recorded the highest DMP among the treatments at 30 DAS and at harvest. Hansen (1972) observed that net photosynthesis in crop plants is primarily influenced by leaf area index. Higher LAI observed in T_4 at 30 DAS and 60 DAS facilitated more light interception which enhanced the photosynthesis and assimilate translocation to different plant parts. The result is in conformity with the observation made by Amanullah *et al.* (2008) reported that light interception increases with increase in

110

leaf area, which ultimately increases the dry matter production. Increased availability and uptake of nutrients led to better expression of growth and yield attributes which also contributed to higher DMP in T_4 at harvest. The finding is in accordance with the observations of Trehan and Sharma (2000) who reported that in maize, DMP increased with the application of zinc. Total DMP significantly increased by priming with one percent Zn (Harris *et al.,* 2007). Favourable influence of Zn on dry matter accumulation in pulses were also reported by several workers (Khorgamy and Farina, 2009; Valenciano *et al.*, 2010; Usman *et al.*, 2014).

5.2.3 Effect of Seed Invgouration Treatments on Physiological Parameters

Leaf area index, an important indicator of plant growth was significantly influenced by seed invigouration treatments. Seed invigouration treatments registered significantly higher LAI at 30 DAS and 60 DAS. The reason might be due to the fact that seed invigouration enhanced the vigour of seedlings which accelerates the leaf development resulting in higher number of leaves with larger leaf area. Chomontoswki *et al.* (2019) reported that seed priming accelerates the leaf development and significantly enhanced the LAI in sugar beet. These treatments also recorded higher number of effective nodules and nodule mass compared to control (Fig. 6 and Fig.7), which will increase the N fixation and N supply to the plants. Shanti *et al.* (1997) observed that increased N supply enhanced the vegetative growth with more photosynthetic surface and higher LAI. At 30 DAS, the treatment T_4 registered higher LAI and it was statistically on par with T_1 (seeds pelleted with borax 50 mg kg^{-1} seed), T_2 (seeds pelleted with borax 100 mg kg^{-1} seed), T_3 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h) and T_5 (T_1 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed). However, at 60 DAS, T_3 registered the highest LAI and it was statistically comparable with T_4 and T_5. Higher LAI recorded in these treatments might be due to the better development of roots and increased availability of nutrients, which might have enable the crop to absorb and translocate sufficient quantity of nutrients to establish good canopy with higher number of leaves and branches (Table 7).

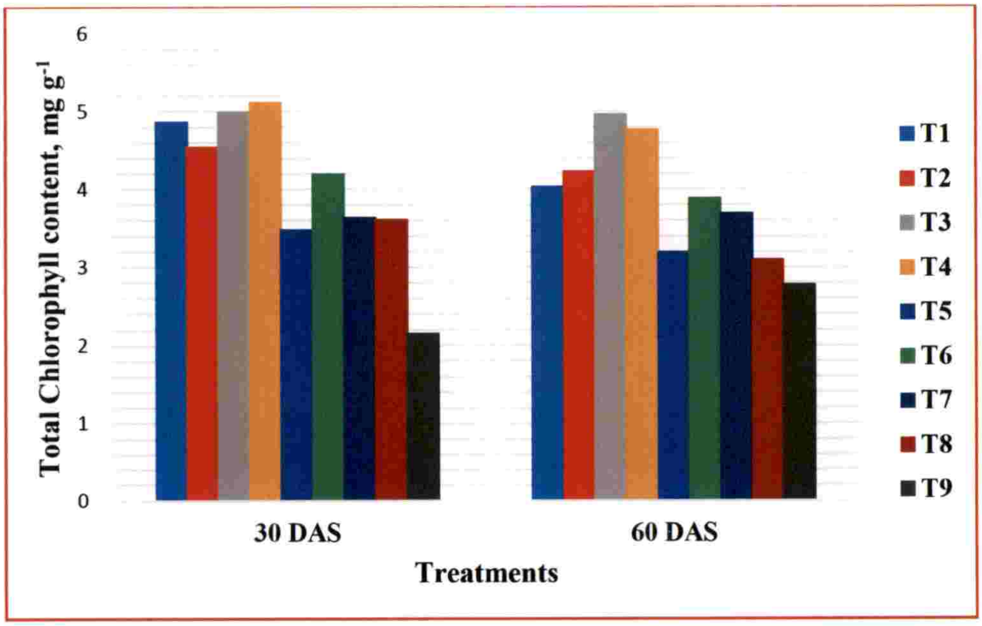


Fig. 5 Effect of seed invigouration treatments on total chlorophyll content of leaves at 30 DAS and 60 DAS, mg g^{-1}

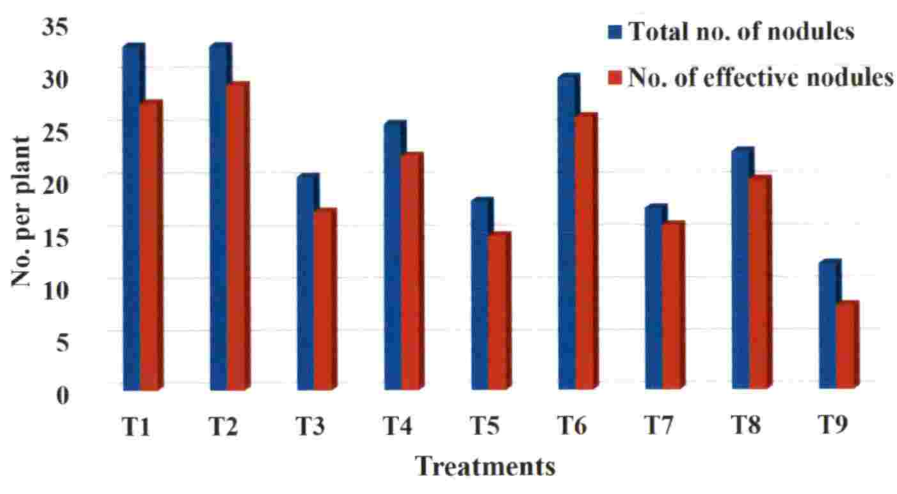


Fig. 6 Effect of seed invigouration treatments on total number of nodules and effective nodules per plant

Moreover, presence of effective nodules with higher nodule mass might have enhanced the N fixation and N assimilation which will also favours vegetative growth. Grindlay (1997) reported that N availability is essential to enhance the leaf area and to maintain the leaf longevity. The present result is in agreement with the findings of Shinde *et al.* (2017) who observed that seed polymer coating with micronutrients enhanced the seedling vigour resulting in good crop establishment leading to better crop growth with large leaf area index.

Seed invigouration treatments significantly influenced the chlorophyll content of leaf. Similar to that of LAI, total chlorophyll content, chlorophyll a and b were higher in seed invigouration treatments. This was owing to the fact that fast and uniform germination and vigorous crop growth achieved due to seed invigouraion might have helped the plant to absorb required quantity of available plant nutrients from the soil which will favour the plant metabolism and chlorophyll synthesis and enhanced the photosynthetic activity. Sathiyanarayanan *et al.* (2015) opined that seed hardening enhanced the absorption of nutrients from the soil. The increased absorption and translocation of nutrients enhanced the chlorophyll synthesis and photosynthetic activity. Among the seed invigouration treatments, seed priming with $ZnSO_4$ 0.025 and 0.05 percent for 4 h recorded higher total chlorophyll, chlorophyll a and chlorophyll b content. The result is in accordance with the findings of Afzal *et al.* (2015) who pointed out that seed priming with Zn increased the chlorophyll content in spring maize. Seeds primed in 0.5 percent $ZnSO_4$ recorded higher chlorophyll a (2.64 mg g^{-1}) and b (1.23 mg g^{-1}) content compared to control (1.57 mg g^{-1} and 0.39 mg g^{-1}, respectively). Seed priming with $ZnSO_4$ might have enhanced the availability of Zn right from seedling to subsequent growth stages of crop growth and increased the nodulation, N fixation, N availability and chlorophyll formation. Sharma *et al.* (2010) reported that Zn plays a major role in chlorophyll formation and enhanced the chlorophyll content of leaf. Enhancement in chlorophyll content due to the application of Zn was that, Zn acts as the structural and catalytic component of proteins, enzymes and a co-factor for the production of chlorophyll biosynthesis (Balashouri, 1995). Hisamitsu *et al.*

(2001) and Kryvoruchko (2017) reported that deficiency of Zn interrupts chloroplast structure and chlorophyll formation.

Crop growth rate and RGR were also significantly influenced by seed invigouration treatments. In general, higher CGR was observed in all the seed invigouration treatments at both the stages of observation. The increase in CGR and RGR values observed in seed invigouration treatments might be due to higher biomass production resulting from higher LAI and total chlorophyll content. At 30 DAS, the treatment T_1 (seeds pelleted with borax 50 mg kg^{-1} seed) recorded higher CGR which was statistically on par with T_2 (seeds pelleted with borax 100 mg kg^{-1} seed) and T_6 (T_2 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed). However, at 60 DAS, T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h) registered higher CGR which was statistically comparable with T_3 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h) and T_1. This might be due to increased DMP (Fig. 3) and dry matter partitioning observed in these treatments. Higher LAI (Fig. 4) and chlorophyll content (Fig. 5) observed in these treatments enhanced the photosynthesis which ultimately increased the dry matter production. The result is in line with the observation made by Amanullah *et al.* (2008) who reported that increase in LAI increases the light interception and total DMP at various growth stages. Afzal *et al.* (2013) reported that seed priming with $ZnSO_4$ 0.5 percent significantly enhanced the CGR in maize. Seed priming significantly improved the CGR and NAR in wheat under moisture stress conditions (Hussain *et al.*, 2013). Higher CGR due to the application of Zn and B was also reported by Wasaya *et al.* (2017) in maize. Relative growth rate was found to decrease from 60 DAS to harvest stage in all treatments compared to 30 DAS to 60 DAS stage. Similar observation was also made by Arun *et al.* (2017) in cowpea. Similar to that of CGR, significantly higher RGR was observed in T_1 (seeds pelleted with borax 50 mg kg^{-1} seed) from 30 DAS to 60 DAS and T_4 (seeds primed in $ZnSO_4$ 0.05 percent) at 60 DAS to harvest stage. This might be due to increased DMP resulting from the enhanced photosynthesis as evident from the data on LAI (Fig. 4) and total chlorophyll content (Fig. 5). Several workers (Cakmak,2008; Khan *et al.*, 2010; Marschner, 2012) reported that Zn and B activated the physiological process *viz.*, chlorophyll formation, enzyme activation and biochemical process which resulted in increased dry matter production.

5.2.4 Effect of Seed Invigouration Treatments on Nodule Number, Nodule Fresh and Dry Weight

Total number of nodules, effective nodules and nodule fresh and dry weight per plant were significantly influenced by seed invigouration treatments. Compared to control, seed invigouration treatments recorded higher number of nodules per plant, effective nodules per plant and nodule fresh and dry weight per plant. Early seedling emergence, better seedling establishment, better root development and root biomass production might have helped in the formation of more nodules in seed invigouration treatments. The present finding is in accordance with the observations of Lhungdim *et al.* (2014) who observed that seed invigouration enhanced the rhizobial population in lentil. Among the treatments, seeds pelleted with borax registered a greater number of total nodules and effective nodules per plant compared to seeds primed in $ZnSO_4$. This was due to the role of B in cell division in the formation of nodule (Brady and Weil, 2002). Zehirov and Georgiev (2003) also observed that B deficiency will inhibit the cell wall development and cell wall permeability which cause reduction in nodule number. Positive effect of nodulation and dry matter content up to four ppm boron solution was also reported by Subasinghe *et al.* (2003). Though the seeds primed in $ZnSO_4$ recorded lesser nodule number compared to seeds pelleted with borax, nodules were bigger in size and hence the fresh weight as well as dry weight of nodules were found to be more. This was mainly because of high Zn availability (Fig. 13) in these treatments. Upadhyay and Singh (2016) reported that Zn has a significant role in N fixation through nodule formation. The growth of symbiotic bacteria inside the nodule depend on the sucrose transport from leaves to root nodule. The transport of sucrose from leaves to root nodule is mediated by Zn (Udvardi and Poole, 2013), also Zn plays a key role in the biosynthesis of leghaemoglobin (Misra *et al.*, 2002; Das *et al.*, 2012). Marsh and Waters (1985) reported that Zn deficiency in legumes reduces the size of nodules. Compared to nodule number, nodule mass was the more reliable

Plate 5. Nodulation in T_4 (seed priming with $ZnSO_4$ 0.05 per cent for 4 h) at 50 per cent flowering compared to control

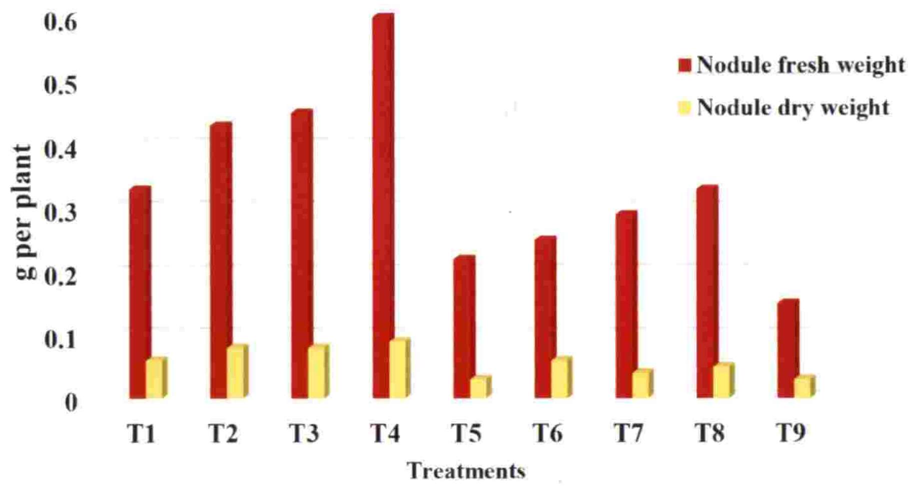


Fig. 7 Effect of seed invigouration treatments on nodule fresh and dry weight of grain cowpea

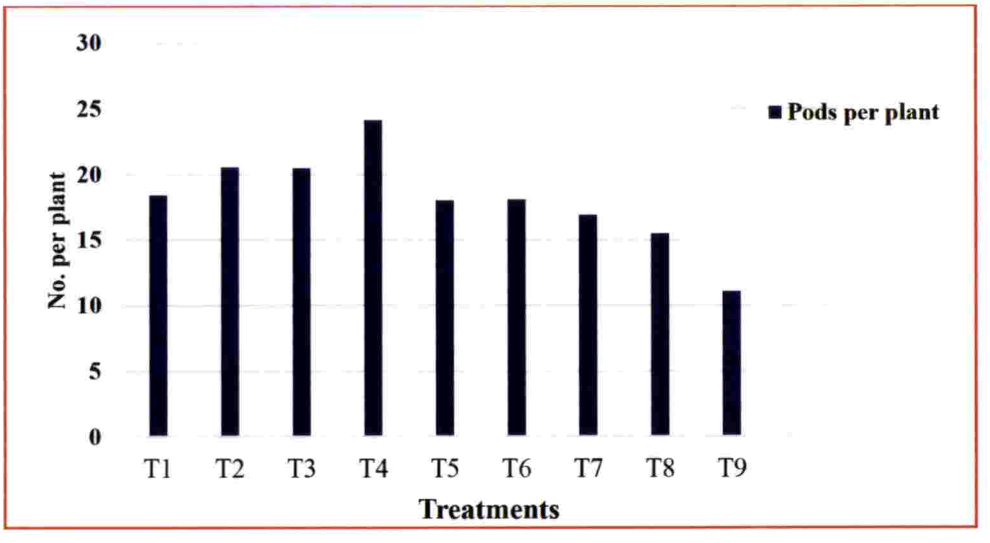


Fig. 8 Effect of seed invigouration treatments on number of pods per plant

measure of nodulation (Kurdali *et al.*, 2002). Increase in nodule weight due to Zn fertilization was also reported by Desta *et al.* (2015) and Debnath *et al.* (2018).

5.2.5 Effect of Seed Invigouration on Yield Attributes of Grain Cowpea

Seed invigouration significantly influenced the yield attributes of grain cowpea. Control treatment registered lesser values for the yield attributes. This might be due to low DMP observed in the treatment (control). Dry matter production is an important growth factor which determines the yield of any crop. Lower DMP observed in control was due to the production of lesser number of green leaves and branches per plant (Table 7) and also due to reduced photosynthesis as manifest from the data on LAI (Fig. 4) and chlorophyll content (Fig. 5). Among the seed invigouration treatments, T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4h) registered higher number of pods per plant, seeds per pod, pod length and pod girth and have taken lesser number of days to attain 50 percent flowering. This might be due to better crop growth and higher DMP achieved through the adequate supply and uptake of nutrients and also due to the increased photosynthesis and efficient translocation of photosynthates from source to sink. Siddiqui *et al.* (2009) opined that during grain formation, with the sufficient supply of Zn, the uptake of N might have increased, which might have improved the yield attributes and yield. Grzebisz *et al.* (2008) also revealed that the uptake of N during the grain formation stage was enhanced due to early stage Zn application. The result is in conformity with the findings of Mohsin *et al.* (2014) who revealed that seed priming with two percent Zn followed by foliar application of Zn (two percent) increased the cob length, cob diameter and 1000 grain weight. Deshpande *et al.* (2009) pointed out that, paprika chilli seeds treated with $ZnSO_4$ + captan + imidacloprid took lesser number of days to flower initiation (37 days) and 50 percent flowering (40.34 days). Shashibhaskar *et al.* (2009) also observed that tomato seeds treated with $ZnSO_4$ 300 mg kg^{-1} seed have taken lesser days for flower initiation and 50 percent flowering (58 and 64, respectively) compared to control (66 and 74 days, respectively). The treatment T_4 (seeds primed in $ZnSO_4$ 0.05

percent for 4 h) recorded higher number of pods per plant and pod weight per plant, pod length and girth. This might be due to the beneficial effect of Zn nutrition. Usman *et al.* (2014) revealed that in green gram Zn nutrition had favourable effect on pod bearing branches per plant, pods per plant and 1000 seed weight. Similar observations were also made by Srimathi *et al.* (2001) in soybean and Masuthi *et al.* (2011) in cowpea. Gacche (2013) who reported that seed pelleting with $ZnSO_4$ 300 mg kg $^{-1}$ seeds recorded significantly higher number of capsules (98.11) and seeds per capsule (49.33) compared to control in sesamum.

5.2.6 Effect of Seed Invigouration Treatments on Yield and Harvest Index

Seed yield per plant was significantly influenced by seed invigouration treatments. Compared to control, all seed invigouration treatments registered higher seed yield. Seed invigouration with Zn and B along with recommended dose of manures and nutrients increased the seed yield from 842 to 1446 kg ha^{-1} in grain cowpea. Fast and uniform germination, high germination percentage (Table 5) and seedling vigour resulting from seed invigouration gave a vigorous start for the crop to continue its growth. This would be resulted in the production of higher number of branches per plant, pods per plant, pods with more length and girth and seeds per pod. Varier *et al.* (2010) revealed that seed invigouration advanced the seed metabolism which has a positive effect in improving the seed performance, earliness in flowering and finally resulted in higher grain yield. Among the treatments, T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h) registered the highest seed yield per plant, which was statistically on par with T_3 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h), T_1 and T_2 (seeds pelleted with borax 50 and 100 mg kg^{-1} seed) and T_6 (T_2 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed). Higher seed yield observed in these treatments might be due to the better expression of yield attributes especially pods per plant resulting from better uptake of nutrients (Fig. 10 and 11). Higher LAI (Fig. 4) and chlorophyll content (Fig. 5) observed in these treatments significantly improved the photosynthetic activity leading to the production of more amount of carbohydrates and translocation of assimilates from source to sink which finally contribute to higher seed yield. Also, higher number of nodules and nodule mass observed in these treatments enhanced the N assimilation, production of proteins and translocation of carbohydrate from source to sink which might have led to the production of higher number of pods per plant which in turn enhanced the seed yield per plant and seed yield ha^{-1}. Masuthi *et al.* (2009) observed that Zn and B plays a major role in pollen germination, fruit setting, seed development and translocation of starch from source to sink. Similar observation was also made by Peda-Babu *et al.* (2007) who observed that Zn fertilization enhanced the carbohydrate synthesis and their transport from source to sink. Role of B in N utilization, protein synthesis and carbohydrate translocation were also reported by Johnson and Albert (1967) and Masuthi *et al.* (2009). Significant increase in the seed yield of green gram due to seed treatment with $ZnSO_4$ 4 g kg^{-1} seed was reported by Usman *et al.* (2014). Higher seed yield due to seed pelleting with B in minor millets was reported by Angamuthu (1991) and by Srimathi *et al.* (2001) in soybean.

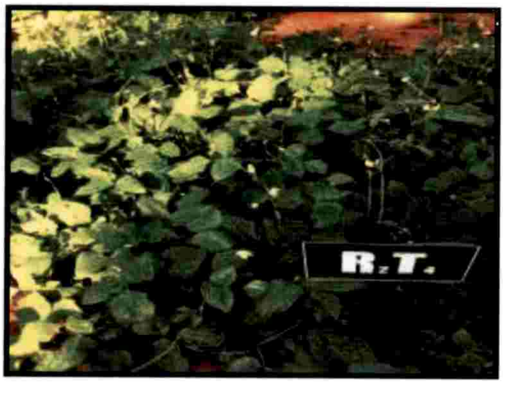
From the results it has been observed that, seed invigouration with Zn or B followed by *Trichoderma viride* seed treatment 10 g kg^{-1} registered lesser seed yield than the treatments without *Trichoderma viride* seed treatment. This might due to the lesser uptake of Zn and B (Fig. 11) and production of lesser number of pods per plant. Several researchers (Howell, 2003; Verma *et al.*, 2007; Segarra *et al.*, 2010) revealed that *Trichoderma* have the ability to release fungal siderophores and the fungal siderophores increase the Fe availability and uptake by crop plants. Dimpka *et al.*, (2009) and Santiago *et al.*, (2011) pointed out that the increased availability of Fe decreased the availability of other micronutrients due to antagonistic effect. The lowest seed yield recorded in control was due to lower dry matter production (Fig. 3), lesser nodulation (Fig. 6 and 7), lesser uptake (Fig. 10 and 11)) and also due to the production of lesser number of pods per plant (Fig. 8). Fageria (1992) reported that in legumes, the number of pods per unit area determined the yield.

Haulm yield was also significantly influenced by seed invigouration treatments. Compared to control, all seed invigouration treatments recorded higher haulm yield. This might be due to better seedling establishment, seedling vigour, better uptake of nutrients and production of higher number of branches per plant and green leaves per plant (Table 7). Haulm yield also followed the same trend as that of dry matter production. Fageria *et al.* (2006) revealed that an increase in the number of leaves and plant height increased the biological yield. Among the treatments, the highest haulm yield per plant and haulm yield ha^{-1} was registered in T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h). This might be due to the better uptake of nutrients which improved the growth attributes, leaf area index, chlorophyll content and CGR. The increase in haulm yield due to Zn fertilization in pulses was also revealed by Shanti *et al.* (2008) and Mahilane and Singh (2018).

Harvest index gave an indication of amount of photosynthates translocated to the economic part of the plant. Seed invigouration treatments significantly influenced the harvest index. Among the treatments, the lowest HI was observed in control. This was due to the lowest grain yield recorded in the treatment. Among the seed invigouration treatments, the treatment T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4h) registered the highest harvest index. This was due to higher seed yield recorded in the treatment. Increased photosynthesis, as evident from data on LAI (Fig. 4) and total chlorophyll content (Fig. 5) at 60 DAS and efficient translocation of photosynthates from source to sink might have contributed to higher seed yield in T_4. Seed priming with $ZnSO_4$ enhances the viability of seeds resulting in fast and uniform germination and seedling vigour. Better crop growth enhanced the absorption of nutrients through root and enhanced the synthesis of IAA, carbohydrate and N metabolism which ultimately led to higher economic yield with higher harvest index. Increased photosynthetic efficiency, assimilation and dry matter production resulting from the better availability and uptake of nutrients was reported by Amjad *et al.* (2004) and Calhor (2006). Usman *et al.*, (2014) observed that HI was significantly improved with the application of 20 kg $ZnSO_4$ ha^{-1}. Similarly, Mohsin *et al.* (2014) who reported that seed priming with two percent Zn followed by foliar application of Zn (two percent) recorded the highest harvest index in maize. Afzal *et al.* (2013) reported that maize seeds primed

8 DAS

30 DAS



Flowering stage

Harvest stage

Plate 6. Performance of best treatment T_4 (seed priming with $ZnSO_4$ 0.05 per cent for 4h) at different growth stages

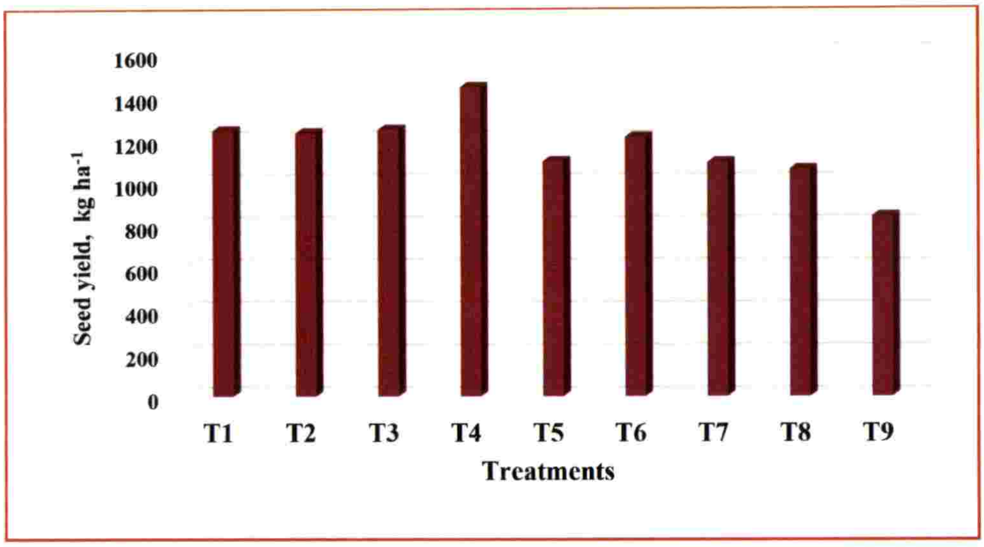


Fig. 9 Effect of seed invigouration treatments on seed yield of grain cowpea, kg ha^{-1}

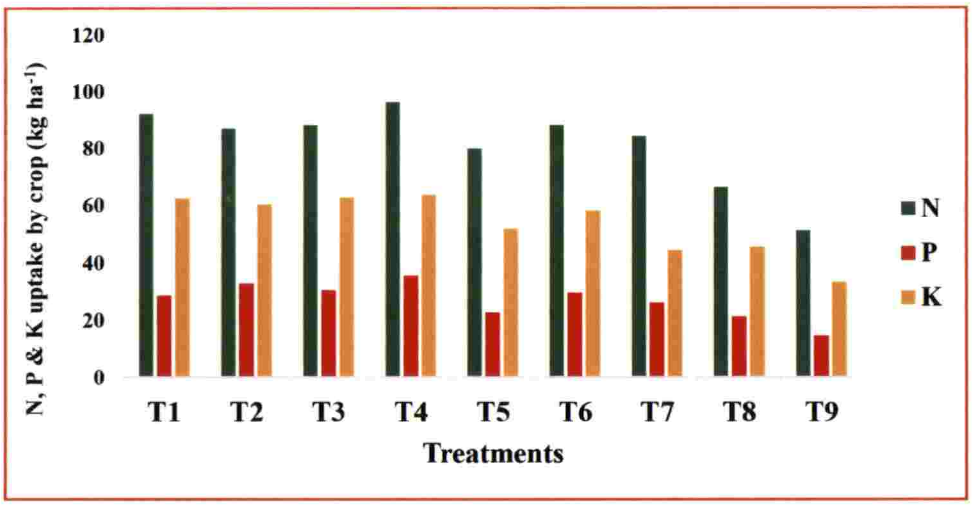


Fig.10 Effect of seed invigouration treatments on total N, P and K uptake by grain cowpea, kg ha^{-1}

in $ZnSO_4$ 1.5 percent increased the harvest index. Khorgamy and Farina (2009) stated that in chick pea, Zn fertilization had significant effect on harvest index.

5.2.7 Effect of Seed Invigouration Treatments on Crude Protein Content of Seed

Crude protein content of grain was significantly influenced by seed invigouration treatments. Compared to control, seed invigouration treatments registered higher seed crude protein content. This might be due to increased N uptake observed in these treatments. Cai *et al.* (2008) revealed that nitrate reductase and glutamine synthase enzymes which play a key role in the integration of N into amino acid during protein synthesis was stimulated under increased N supply which might have enhanced the crude protein content in seed. Adequate Zn and B availability enhanced the N metabolism which might have increased the synthesis of amino acids (Suman, 2018). Sudha and Stalin (2015) reported that increased build-up of amino acids enhanced the protein synthesis and protein content in rice grain. Among the treatments, the highest crude protein content observed in T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h) was due to higher N and Zn uptake by seed (Fig.10 and 11). Since, Zn plays a key role in the translocation of starch from source to sink, carbohydrate and N metabolism, adequate Zn availability improved the seed quality (Taliee and Sayadian, 2000). Improvement in protein content of grain legumes due to Zn fertilization was reported by several workers (Singh and Singh, 2012; Ram and Katiyar, 2013; Samreen *et al.*, 2017 and Kuniya *et al.*, 2018).

5.2.8 Effect of Seed Invigouration Treatments on Anthracnose Incidence in Grain Cowpea

Seed invigouration had significant effect on anthracnose disease incidence in grain cowpea. Compared to control, seed invigouration treatments recorded lesser percentage incidence of anthracnose and the lowest incidence was recorded in T_4 (seed priming with $ZnSO_4$ 0.05 percent for 4 h). Lower incidence of anthracnose observed in seed priming and pelleting with borax and $ZnSO_4$ might be due to the increased seedling vigour observed in these treatments and also due to the role of zinc and boron in pest and disease suppression. Zn plays a major role in disease tolerance. Since zinc act as a cofactor of many enzymes, it plays a major role in crop physiology (Brown *et al.*, 2002). Pandey *et al.* (2002) revealed that, as an activator of Cu/Zn superoxide dismutase, Zn is involved in membrane protection against oxidative damage through the detoxification of superoxide radicals (Cakmak, 2000). Wadhwa *et al.* (2014) opined that Zn nutrition increased the antioxidant enzyme activity in plants which provides resistance against fungal diseases. Boron promotes the stability and rigidity of cell wall structure and therefore supports the shape and strength of the plant cell (Brown *et al.,* 2002). Since, B is possibly involved in the structural integrity of plasma membrane (Dordas and Brown, 2005), B nutrition reduces disease incidence in crop plants. Graham and Webb (1991) reported that B reduces the diseases caused by *Plasmodiophora brassicae* in crucifers, *Fusarium solani* in bean, *Verticillium albo-atrum* in tomato and cotton, tobacco mosaic virus in bean, tomato yellow leaf curl virus in tomato and *Blumeria graminis* in wheat (Marshner, 1995). The lesser incidence of anthracnose in T_5 and T_6 (seeds pelleted with borax 50 and 100 mg kg^{-1} seed + *Trichoderma viride* seed treatment 10 g kg^{-1} seed) and T_7 and T_8 (seed priming with $ZnSO_4$ 0.025 and 0.05 percent for 4 h + *Trichoderma viride* seed treatment 10 g kg^{-1} seed) might also be due to the antagonistic effect of *Trichoderma viride* on the growth of *Colletotrichum*. Amin *et al.* (2014) reported that seed treatment with *Trichoderma viride* reduced the anthracnose disease incidence in Haricot bean compared to control.

5.2.9 Effect of Seed Invigouration Treatments on Nutrient Uptake by Crop

Uptake of N, P, K, Zn and B uptake by the crop at harvest was markedly influenced by seed invigouration treatments. Compared to control, seed invigouration treatments registered higher uptake, due to higher dry matter production recorded in these treatments. Nutrient uptake by crop is related to nutrient content in the plant and dry matter production; dry matter production in turn depends on the photosynthetic ability of the plant. Enhanced seedling vigour resulting from the fast and uniform crop establishment might have led to the development of higher number of branches with more leaves with higher leaf area and chlorophyll content. This might have increased the photosynthetic rate and uptake of nutrients in seed invigouration treatments. Tabassum *et al.* (2013) observed that increased availability of nutrients also accelerated the physiological processes which in turn influenced the DMP and nutrient uptake.

Among the seed invigouration treatments, total uptake as well as grain uptake of N, P and K was the highest in T_4 (seed priming with $ZnSO_4$ 0.05 percent for 4 h). This might be due to higher dry matter accumulation (Fig. 3) and higher content of N, P and K registered in the treatment. Higher uptake of N, P and K by the seed in T_4 might be due to the role of Zn in activating the enzymes present in the chloroplast and cytoplasm *viz.*, carbonic anhydrase, fructose-1, 6-bisphosphate and aldolase enzymes and this will lead to the transport of photosynthates from source to sink. Marshner and Cakmak (1989) pointed out that deficiency of Zn resulting in the accumulation of carbohydrate in plant leaves. Pooniya and Shivay (2013) pointed out that Zn fertilization significantly improved the N and K uptake in Basmati rice grain and straw. Khattak *et al.* (2006) reported that Zn nutrition improved the N uptake by maize crop. Similarly, Karki *et al.* (2005) observed an increase in the uptake of nutrients due to Zn fertilization. Higher seed yield recorded in T_4 might also be due to higher uptake of nutrients.

Zinc and B uptake were also significantly influenced by seed invigouration treatments. Seed invigouration treatments recorded higher uptake of Zn and B compared to control. Better crop growth attained by the early establishment of seedlings might have resulted in better absorption and uptake of major nutrients along with micronutrients Zn and B. Among the seed invigouration treatments, treatments involving $ZnSO_4$ priming registered higher Zn uptake by the grain. This result is in consonance with the observation of Harris *et al.* (2007) who observed that Zn priming enhanced the Zn concentration of wheat grain by 12 percent, chickpea by 29 percent and maize by 19 percent. In the present experiment, cowpea

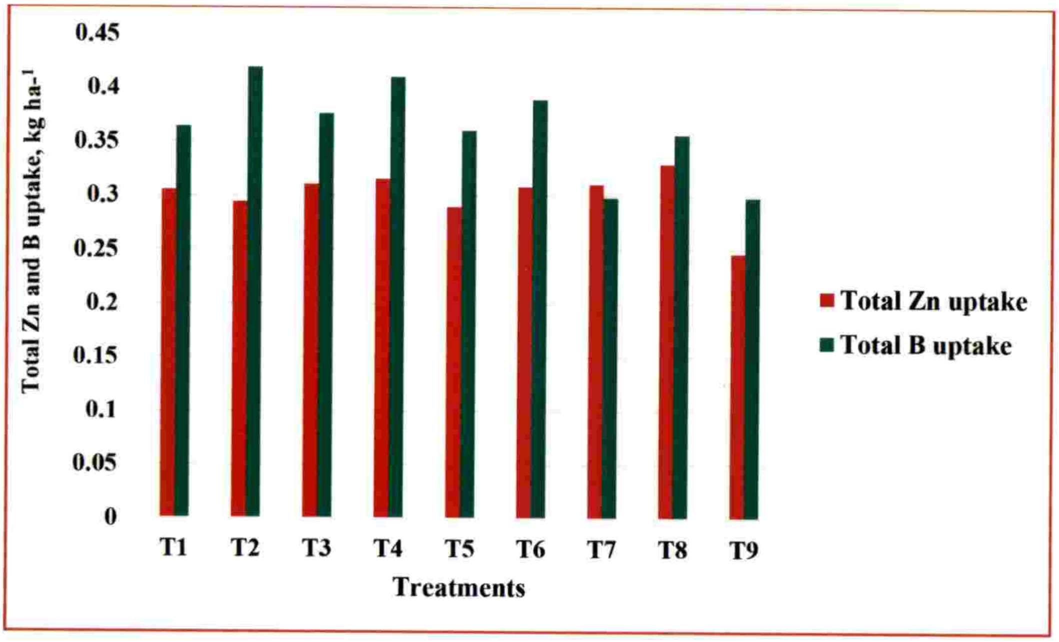


Fig.11 Effect of seed invigouration treatments on total Zn and B uptake by crop, kg ha^{-1}

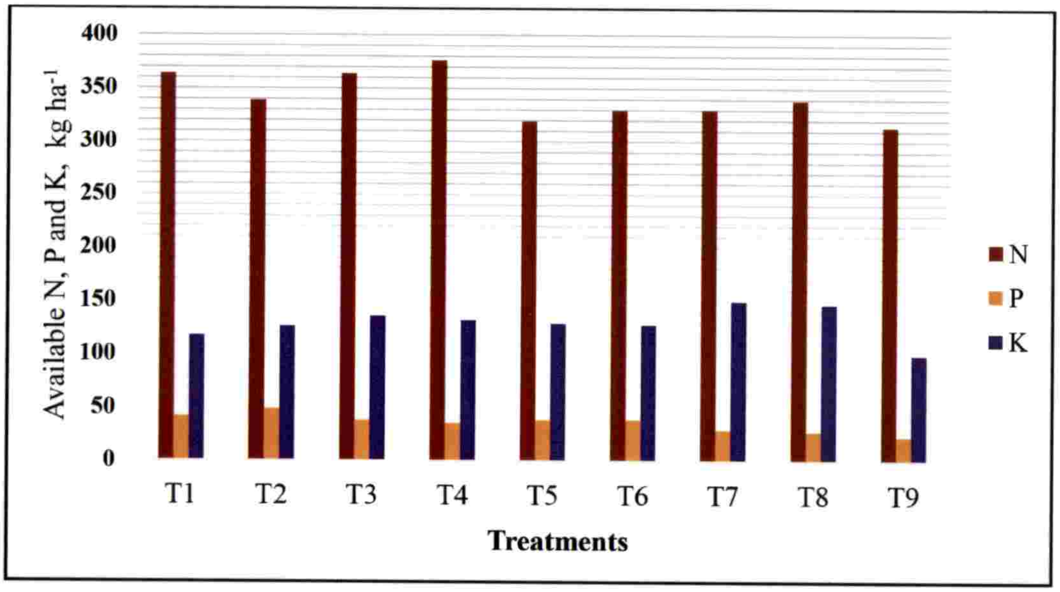


Fig.12. Effect of seed invigouration treatments on available N, P and K status of soil after the experiment, kg ha^{-1}

seeds primed in $ZnSO_4$ 0.05 percent enhanced the Zn uptake of seed by 40.2 per cent. The result is in agreement with the observation of Harris *et al.* (2007) who observed that Zn priming significantly increased the grain Zn concentration in maize and is a low-cost technology to augment the Zn content in grain. Slaton *et al.* (2001) and Miraj *et al.* (2013) also reported that nutripriming significantly enhanced the Zn uptake by rice seedlings. Borax pelleted seeds also recorded higher Zn uptake compared to control. The result is in conformity with the observation of Debnath *et al.* (2018) who observed that application of B along with recommended dose of fertilizers increased the B uptake in grain cowpea. The B uptake by grain was the highest in $ZnSO_4$ primed seeds than in borax pelleted seeds. Sinha *et al.* (2000) observed a positive Zn x B interaction in mustard.

5.2.10 Effect of Seed Invigouration Treatments on Economics

Economic evaluation of treatments is of great relevance for its acceptance in the farmers field. Seed invigouration treatments significantly influenced the net income and B:C ratio. Control treatment recorded the lowest net returns and B:C ratio. This was due to the lowest seed yield recorded in the treatment. Seed invigouration treatments resulted in an increase in net income of ₹ 17, 310 ha^{-1} to ₹ 48,001 ha^{-1} compared to control (Fig. 14). This was owing to the fact that fast and uniform emergence of seedlings with vigourous growth resulting in the better expression of yield attributing characters particularly pods per plant which in turn lead to higher seed yield. Better utilization of nutrients due to early emergence of seedlings resulted in higher grain yield in cereal crops was reported by Badiri *et al.* (2014). Among the seed invigouration treatments, higher net income was recorded in T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4 h), this might be due to higher grain yield recorded in the treatment. Harris *et al.* (2007) observed that monetary benefits are high in seed priming with one percent solution of Zn compared to soil application of 2.75 kg Zn ha^{-1} in maize. Benefit cost ratio was also significantly influenced by seed invigouration treatments. It followed the similar trend as that of net income and the highest B:C ratio was registered in T_4. The result is in conformity with the observations of Harris *et al* (2007) who observed that $ZnSO_4$

priming enhanced the grain yield of maize by two times and is a low-cost technology which can be easily adopted by resource poor farmers.

5.2.11 Effect of Seed Invigouration on Post Harvest Organic Carbon and Available N, P, K, Zn and B Content in the Soil

As compared to initial nutrient status, nutrient status of soil after the experiment was improved. This was due to the fact that, being a leguminous crop, cowpea have the ability to fix atmospheric N and tap nutrients from deeper layers (Melero *et al.*, 2007). The result is in consonance with the observation of Amanullah *et al.* (2007). Thamburaj (1991) revealed that raising legumes in rotation increased the NPK content of soil. Wani *et al.* (2002) and Jensen *et al.* (2012) also reported that inclusion of legumes in rotation significantly improved the soil organic carbon and available nutrients in the soil.

Post-harvest organic carbon content of soil was significantly influenced by seed invigouration treatments. In general, an enhancement in organic carbon content of soil was observed in all the treatments compared to initial soil status. The enhancement in organic carbon content observed in all the treatments might be due to the uniform application of FYM 20 t ha^{-1}, biological N fixation, addition of organic residues and exudation of root exudates in to the soil by the crop root as well as the symbiotic N fixing bacteria associated with the crop. Seed invigouration treatments registered higher organic carbon content compared to control. This might be due to the enhanced crop growth resulting from the better seedling establishment and improved nodulation observed in these treatments. Lynch and Whips (1990) revealed that about 40 percent of dry matter accumulated by the plant was released into the rhizosphere as root exudates. Among the seed invigouration treatments, higher organic carbon content was observed in T_4 (seeds primed in $ZnSO_4$ 0.05 percent for 4h) which was statistically comparable with T_1 and T_2 (seeds pelleted with borax 50 and 100 mg kg^{-1} seed), T_3 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h) and T_8 (T_1 + *Trichoderma viride* seed treatment 10 g kg $seed^{-1}$) . This was also due to the increased nodulation (Fig. 6 and 7) and higher dry matter production (Fig. 3) observed in these treatments. Organic substances (organic acid, amino acid, sugars, vitamins, mucilage *etc.*) released into the rhizosphere during the crop growth as well as due to the addition of organic matter in the form of FYM and leaf fall might have enhanced the organic carbon content of soil (Hasanuzzaman *et al.*, 2019).

Available N, P, K, Zn and B status of soil was also significantly influenced by seed invigouration treatments. Compared to control, all seed invigouration treatments registered higher availability of N, P, K, Zn and B. The better crop establishment and better rooting allow the crop to tap nutrients from the deeper layers. Further organic matter addition due to the falling of senescent leaves and atmospheric N fixation by the symbiotic N fixing bacteria present in the nodule also contribute to the increased availability of N, P and K. Chatterjee and Bandyopadhyay (2017) reported that seed treatment with micronutrients have prominent effect on the availability of major nutrients.

The available N status of all the treatments are in medium range. Availability of N was found to be higher in treatments with higher organic carbon content. The result is in accordance with the findings of Sakin (2012) who reported that high soil organic carbon enhanced the N content of the soil. Available P status in the soil after the experiment was found to be high in all the treatments. However, the treatments having high Zn content registered lower available P content compared to those treatments having low Zn content. This might be due to the antagonism exists between Zn and P and also due to the formation of insoluble zinc phosphate. Similar observations were also made by Balai *et al.* (2017). Available K status was comparatively higher in treatment T_7 and T_8 (seeds primed in $ZnSO_4$ 0.025 and 0.05 percent + *Trichoderma viride* seed treatment 10 g kg^{-1} seed) compared to other seed invigouration treatments which might be due to lower K uptake registered in these treatments (Fig. 10).

Seed invigouration treatments registered higher available Zn and B content in soil compared to control. This might be due to the fact that higher soil organic carbon content prevented the leaching of nutrients and sustained the soil fertility status. Similar observation was also made by Suman (2018). Among the seed invigouration treatments, the treatments having higher post-harvest Zn content registered lower B content. This might be due to the antagonistic effect of Zn on B. The result is in agreement with the findings of Mullah *et al.* (2015) and Hosseini *et al.* (2007) who observed that higher Zn availability in soil decreased the B availability in soil.

The present study revealed the importance of seed invigouration of micronutrients *viz*, Zn and B in the production of grain cowpea. Seed invigouration with zinc and boron had significant effect in enhancing seed germination, seedling vigour, nodulation, growth and yield attributes and seed yield of grain cowpea. Considering the seed yield and economics, seed priming with 0.05 percent $ZnSO_4$ for 4h along with recommended dose of manures and fertilizers could be recommended for better plant establishment and enhanced production and productivity of grain cowpea.

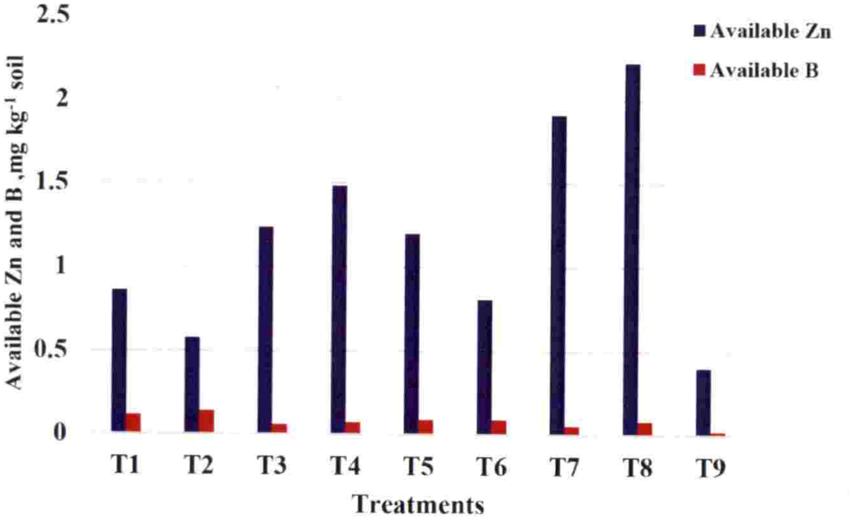


Fig.13 Effect of seed invigouration treatments on available Zn and B status of soil after the experiment, mg kg^{-1} soil

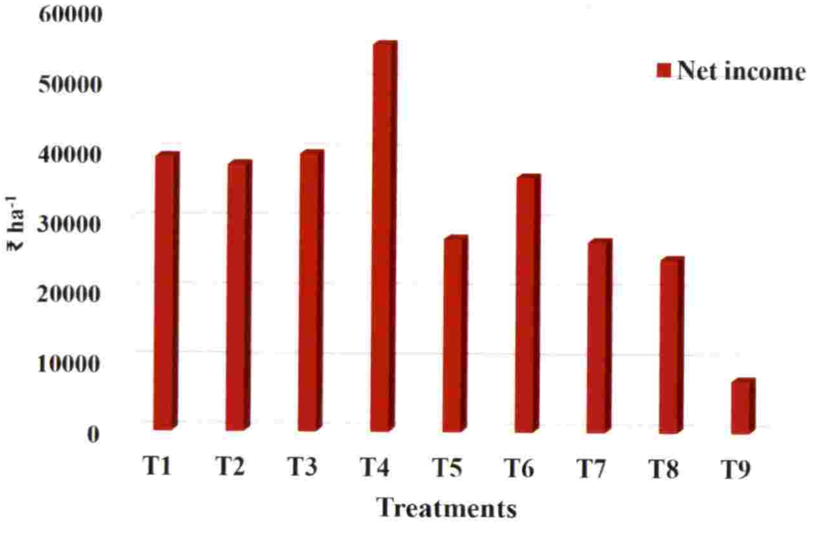


Fig. 14 Effect of seed invigouration treatments on net income of grain cowpea, ₹ ha^{-1}

Summary

6. SUMMARY

The research work entitled "Seed invigouration for yield enhancement in grain cowpea (*Vigna unguiculata* L.Walp)" was conducted with an objective to evaluate the effect of seed invigouration with zinc sulphate and borax on grain cowpea and to assess its effect along with *Trichoderma viride* on the growth and yield of the crop. The research work comprised of two experiments, a pot culture experiment and a field experiment. The experiments were carried out during *Rabi* season 2018 at Coconut Research Station, Balaramapuram. Salient findings of the experiments were summarised below.

Pot culture experiment was laid out in completely randomized block design with thirteen treatments in three replications. The treatments comprised of six pelleting treatments *viz.*, T_1 and T_2 (seeds pelleting with $ZnSO_4$ 100 and 200 mg kg^{-1} seed), T_3 andT_4 (seeds pelleting with borax 50 and 100 mg kg^{-1} seed) , T_5 and T_6 ($ZnSO_4$ 100 mg + borax 50 mg kg^{-1} seed and $ZnSO_4$ 200 mg + borax 100 mg kg^{-1} seed) and six priming treatments *viz.*, T_7 and T_8 (seed priming with $ZnSO_4$ 0.025 and 0.05 percent for 4h) , T_9 and T_{10} (seed priming with borax 0.01 percent and 0.02 percent for 4 h), T_{11} and T_{12} (seed priming with $ZnSO_4$ 0.025 + borax 0.01percent for 4 h and $ZnSO_4$ 0.05 + borax 0.02 percent for 4 h) and a control (T_{13}).

Seed pelleting with borax 50 and 100 mg kg^{-1} seed and seed priming with $ZnSO_4$ 0.025 and 0.05 percent recorded higher GP, MDG, SG, GI, GRI, CRG, SVI I and SVI II and lesser MGT and T_{50}. Hence, seed pelleting with borax 50 and 100 mg kg^{-1} seed and seed priming with $ZnSO_4$ 0.025 and 0.05 percent which showed fast, uniform synchronous emergence with high vigour index were selected as the two best seed pelleting and priming treatments for field experimentation.

The field experiment was laid out in randomized block design with nine treatments in three replications. The treatments comprised of T_1 -seed pelleting with borax 50 mg kg^{-1} seed, T_2 -seed pelleting with borax 100 mg kg^{-1} seed, T_3 -seed priming with $ZnSO_4$ 0.025 percent for 4 h, T_4 -seed priming with $ZnSO_4$ 0.05

percent for 4 h, T_5 -T_1 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed, T_6 -T_2 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed,T_7 -T_3 + *Trichoderma viride* seed treatment10 g kg^{-1} seed,T_8 -T_4 + *Trichoderma viride* seed treatment 10 g kg^{-1} seed and T_9 -control.

Seed invigouration treatments had significant effect on growth parameters *viz.*, number of branches per plant, number of green leaves per plant and DMP at 30 DAS, 60 DAS and at harvest. However, plant height was not significantly influenced by seed invigouration treatments. Seed priming with $ZnSO_4$ 0.05 percent for 4 h alone (T_4) or seed priming with $ZnSO_4$ 0.05 percent for 4 h +*Trichoderma viride* seed treatment 10 g kg^{-1} seed (T_7) recorded significantly higher number of branches and green leaves per plant at 30 DAS and 60 DAS. At 30 DAS and harvest, the treatment T_4 recorded the highest DMP, however at 60 DAS, the highest DMP was observed in T_1 (seeds pelleted with borax 50 mg kg^{-1} seed).

Seed invigouration treatments recorded significantly higher LAI at 30 DAS and 60 DAS compared to control. Among the treatments, at 30 DAS, seed priming with $ZnSO_4$ 0.05 percent for 4 h (T_4) recorded the highest LAI (4.36) and at 60 DAS, seed priming with $ZnSO_4$ 0.025 percent for 4 h (T_3) recorded the highest LAI (5.99).

Compared to control, seed invigouration treatments recorded higher CGR and RGR from 30 DAS to 60 DAS and from 60 DAS to harvest. From 30 DAS to 60 DAS, the highest RGR (45.22 mg g^{-1} day^{-1}) and CGR (11.463 g^{-1} day^{-1}) were recorded in T_1 (seed pelleting with borax 50 mg kg^{-1} seed), however from 60 DAS to harvest stage, T_4 (seed priming with $ZnSO_4$ 0.05 percent for 4 h) recorded the highest RGR (25.82 mg g^{-1} day^{-1}) and CGR (17.369 g^{-1} day^{-1}).

Among the treatments, seed priming with $ZnSO_4$ 0.05 percent for 4 h (T_4) recorded the highest total chlorophyll content (5.113 mg g^{-1}) at 30 DAS and seed priming with $ZnSO_4$ 0.025 percent for 4 h (T_3) recorded the highest total chlorophyll content (4.956 mg g^{-1}) at 60 DAS.

Nodule parameters were also significantly influenced by seed invigouration treatments. The treatment, T_1 (seed pelleting with borax 50 mg kg^{-1} seed) and T_2 (seed pelleting with borax 100 mg kg^{-1} seed) recorded the highest total number of nodules per plant whereas the treatment T_2 recorded the highest number of effective nodules per plant. However, the treatment T_4 (seed priming with $ZnSO_4$ 0.05 percent for 4 h) recorded the highest nodule fresh weight (0.60 g) and dry weight (0.09 g) per plant.

Seed invigouration treatments, significantly influenced pods per plant, pod length, pod girth and pod weight, while days to 50 percent flowering, seeds per pod and 100 seed weight were not significantly influenced by seed invigouration. Among the treatments, T_4 (seed priming with $ZnSO_4$ 0.05 percent for 4 h) recorded the highest values for pods per plant, pod length, pod girth and pod weight per plant.

Seed invigouration treatments recorded significantly higher seed yield than the control. Among the seed invigouration treatments, the treatments with *Trichoderma viride* seed treatment 10 kg $seed^{-1}$ registered lesser yield (T_5, T_6, T_7 and T_8) than the treatments without *Trichoderma viride* seed treatment (T_1, T_2, T_3 and T_4). The treatment T_4 (seed priming with $ZnSO_4$ 0.05 percent for 4 h) recorded the highest seed yield $plant^{-1}$ and seed yield ha^{-1} (1446 kg ha^{-1}) and was on par with T_1 and T_2 (seed pelleted with borax 50 and 100 mg kg^{-1} seed), T_3 (seed priming with $ZnSO_4$ 0.025 percent for 4h) and T_6 (T_2 + *Trichoderma viride* seed treatment 10g kg^{-1} seed). Haulm yield per plant, haulm yield ha^{-1} and harvest index followed the same trend as that of seed yield per plant and seed yield per hectare.

Among the treatments, seed priming with $ZnSO_4$ 0.05 percent for 4h (T_4) recorded the highest crude protein content of seed (27.11percent) and the control (T_9) recorded the lowest crude protein content.

In general, seed invigouration treatments recorded lower incidence of anthracnose than the control and the lowest disease incidence (20.7 percent) of anthracnose was recorded in T_4 (seed priming with $ZnSO_4$ 0.05 percent for 4h).

Seed invigouration treatments significantly influenced the N, P, K, Zn and B uptake by crop. Among the treatments, the treatment T_4 (seed priming with $ZnSO_4$ 0.05 percent for 4 h) recorded the highest total N, P and K uptake, The highest Zn uptake was observed in T_8 (seed priming with $ZnSO_4$ 0.05 percent for 4h + *Trichoderma viride* 10 g kg^{-1} seed) and B uptake in T_2 (seed pelleting with borax 100 mg kg^{-1} seed).

Seed invigouration treatments also had significant effect on post-harvest organic carbon and available N, P, K, Zn and B content of soil. Among the treatments, seed priming with $ZnSO_4$ 0.05 percent for 4h (T_4) recorded the highest soil organic carbon content (1.018 percent) and soil available N (376.61 kg ha^{-1}). The highest soil available P was registered in T_2 (seed pelleted with borax 100 mg kg^{-1} soil) and available K in T_7 (seeds primed in $ZnSO_4$ 0.025 percent for 4 h + *Trichoderma viride* seed treatment10 g kg^{-1} seed). The treatment T_8 (T_4 + *Trichoderma viride* 10 g kg^{-1} seed) recorded the highest soil available Zn and T_2 recorded the highest soil available B.

Net income and B: C ratio were also significantly influenced by seed invigouration treatments. Among the treatments, T_4 (seed priming with $ZnSO_4$ 0.05 percent for 4h) recorded higher net income. The B: C ratio was also the highest in T_4, but it was statistically on par with T_1 (seed pelleted with borax 50 mg kg^{-1} seed), T_2 (seed pelleted with 100 mg kg^{-1} seed), T_3 (seed priming with $ZnSO_4$ 0.025 percent for 4 h) and T_6 (seed pelleted with 100 mg kg^{-1} seed + *Trichoderma viride* seed treatment 10 g kg^{-1} seed).

Considering the growth attributes, physiological parameters, yield attributes, disease incidence, nutrient uptake, seed yield and economics, T_4 (seed priming with $ZnSO_4$ 0.05 percent for 4h) can be recommended for better crop establishment and higher seed yield in grain cowpea.

Future line of work

- For the confirmation of results, the experiment has to be repeated for one or more seasons and also with different varieties.
- Seed pelleting and priming with zinc sulphate and borax followed by *Trichoderma viride* seed treatment recorded lesser seed yield and hence a detailed study can be taken up to find out the antagonistic/ synergistic effect of *Trichoderma viride* with Zn and B.
- Study can also be taken up to find out the production of siderophore by the *Trichoderma viride* and its effect on Fe, Zn and B uptake by grain cowpea.

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150

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151

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Abstract

165

ABSTRACT

The study entitled "Seed invigouration for yield enhancement in grain cowpea (*Vigna unguiculata* L.Walp)" was undertaken during 2017-2019, at College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, with the objectives to assess the effect of seed invigouration with zinc sulphate and borax on grain cowpea and to evaluate its effect along with *Trichoderma viride* on growth and yield of the crop.

Research work comprised of one pot culture experiment and a field experiment which were carried out at Coconut Research Station, Balaramapuram. The variety used for the study was Bhagyalakshmy. Pot culture experiment was laid out in completely randomized block design with thirteen treatments and three replications during *Rabi* 2018. The treatments comprised of six pelleting treatments *viz.*, T_1 and T_2 (seeds pelleting with $ZnSO_4$ 100 and 200 mg kg^{-1} seed), T_3 and T_4 (seeds pelleting with borax 50 and 100 mg kg^{-1} seed) , T_5 and T_6 ($ZnSO_4$ 100 mg + borax 50 mg kg^{-1} seed and $ZnSO_4$ 200 mg + borax 100 mg kg^{-1} seed) and six priming treatments *viz.*, T_7 and T_8 (seed priming with $ZnSO_4$ 0.025 and 0.05 per cent for 4 h) , T_9 and T_{10} (seed priming with borax 0.01 per cent and 0.02 per cent for 4 h), T_{11} and T_{12} (seed priming with $ZnSO_4$ 0.025 + borax 0.01 per cent for 4 h and $ZnSO_4$ 0.05 + borax 0.02 per cent for 4 h) and a control (T_{13}).

Seed pelleting with borax 50 and 100 mg kg^{-1} seed and seed priming with $ZnSO_4$ 0.025 and 0.05 per cent recorded higher germination percentage, mean daily germination, speed of germination, germination index, germination rate index, co-efficient of rate of germination, seedling vigour index I and II and lesser mean germination time and time taken for 50 per cent germination. Hence, seed pelleting with borax 50 and 100 mg kg^{-1} seed and seed priming with $ZnSO_4$ 0.025 and 0.05 per cent which showed fast, uniform synchronous emergence with high vigour index were selected as the two best seed pelleting and priming treatments for field experimentation.

The field experiment was laid out in randomized block design with nine treatments and three replications during *Rabi* 2018. The treatments comprised of seed pelleting with borax 50 and 100 mg kg^{-1} seed; seed priming with $ZnSO_4$ 0.025 and 0.05 per cent for 4h; seed pelleting with borax 50 and 100 mg kg^{-1} seed + *Trichoderma viride* seed treatment 10 g kg^{-1} seed and seed priming with $ZnSO_4$ 0.025 and 0.05 per cent for 4h + *Trichoderma viride* seed treatment 10 g kg^{-1} seed and a control.

Results revealed that seed invigouration had significant effect on growth parameters, physiological parameters, yield attributes, yield, protein content, nutrient uptake, post-harvest nutrient availability, disease incidence and economics.

Seed priming with $ZnSO_4$ 0.05 per cent for 4h and seed priming with $ZnSO_4$ 0.05 per cent for 4h + *Trichoderma viride* seed treatment 10 g kg^{-1} seed recorded higher number of branches per plant and green leaves per plant. However, seed priming with $ZnSO_4$ 0.05 per cent for 4h recorded the highest dry matter production at harvest.

Leaf area index and total chlorophyll content were found to be significantly higher in seeds primed in $ZnSO_4$ 0.025 and 0.05 per cent for 4h at both 30 and 60 days after sowing (DAS). During 30 to 60 DAS, crop growth rate (CGR) and relative growth rate (RGR) were the highest in seeds pelleted with borax 50 mg kg^{-1} seeds and during 60 DAS to harvest, seeds primed in $ZnSO_4$ 0.05 per cent for 4h registered the highest CGR and RGR.

Total number of nodules and effective nodules per plant were found to be significantly higher in seeds pelleted with 50 and 100 mg kg^{-1} seed. However, the fresh and dry weight of nodules were the highest in seeds primed in $ZnSO_4$ 0.05 per cent for 4h.

Pods per plant, pod weight per plant, pod length, pod girth, seed yield per plant, seed yield ha^{-1} and harvest index were the highest in seeds primed in $ZnSO_4$ 0.05 per cent for 4h. Among the seed pelleting treatments, seeds pelleted with borax 50 and 100 mg kg^{-1} seed recorded higher seed yield. Seed priming with $ZnSO_4$ either with 0.025 or 0.05 per cent or pelleting with borax either with 50 or 100 mg

kg^{-1} seed recorded higher seed yield than seed priming with $ZnSO_4$ or pelleting with borax combined with *Trichoderma viride* seed treatment 10 g kg^{-1} seed.

Total NPK uptake by crop was the highest in seed priming with $ZnSO_4$ 0.05 per cent for 4h. However, seed priming with $ZnSO_4$ 0.05 per cent for 4h + *Trichoderma viride* seed treatment 10 g kg^{-1} seed recorded the highest Zn uptake and seeds pelleted with borax 100 mg kg^{-1} seed recorded the highest B uptake.

Results on nutrient status of soil after the experiment revealed that seeds primed in $ZnSO_4$ 0.05 per cent for 4h recorded the highest organic carbon content and available N status. Seeds pelleted with borax 100 mg kg^{-1} seed recorded the highest available P and seeds primed in $ZnSO_4$ 0.05 per cent + *Trichoderma viride* seed treatment 10 g kg^{-1} seed recorded the highest available K status. Seed priming with $ZnSO_4$ 0.05 per cent for 4h recorded the highest available soil Zn status, whereas, seed pelleting with borax 100 mg kg^{-1} seed recorded the highest available soil B status.

Seed invigouration treatments recorded significantly higher crude protein content than control and the highest crude protein content was recorded in seed priming with $ZnSO_4$ 0.05 per cent for 4h.

Seed invigouration treatments recorded lower incidence of anthracnose disease than the control and among the treatments, the lowest incidence was recorded in seed priming with $ZnSO_4$ 0.05 per cent for 4h.

The net returns and benefit cost ratio were the highest in seeds primed in $ZnSO_4$ 0.05 per cent for 4h.

Considering the yield attributes, yield, disease incidence, and economics seed priming with $ZnSO_4$ 0.05 per cent for 4h along with recommended dose of FYM (20 t ha^{-1}), lime (250 kg ha^{-1}) and NPK (20:30:10 kg ha^{-1}) could be recommended for better plant establishment and higher yield in grain cowpea.

Appendix

APPENDIX 1

Weather data during the crop season (10/11/2018- 04/02/2019)

Standard week	Temperature (^{0} C)		RH (%)		Rainfall (mm)
	Maximum	Minimum	Maximum	Minimum	
45	30.85	17.50	91.00	59	5.8
46	31.87	17.62	90.80	71	52.8
47	32.96	17.61	87.30	73	46.2
48	33.31	17.90	81.71	70	2.0
49	32.93	18.22	90.70	66	16.4
50	32.62	17.83	92.60	71	25.8
51	32.21	17.10	92.14	62	-
52	32.54	17.31	91.30	60	21.2
1	33.10	14.90	97.00	67	-
2	33.07	14.20	94.14	87	-
3	33.50	15.12	92.50	74	-
4	33.60	14.90	99.70	76	-
5	34.00	16.42	96.00	70	4.8

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"വൻപയറിന്റെ വിളവ് വർദ്ധനവിന് വിത്തുപചാരം" എന്ന വിഷയത്തെ ആസ്പദമാക്കിയ ഗവേഷണ പഠനം 2018-19 കാലയളവിൽ വെള്ളായണി കാർഷിക കോളേജിൽ നടത്തുകയുണ്ടായി. ഇതിനായുള്ള വിളഭൂമി പരീക്ഷണം ബാലരാമപുരത്തുള്ള തെങ്ങ് ഗവേഷണ കേന്ദ്രത്തിൽ 2018 നവംബർ മുതൽ 2019 ഫെബ്രുവരി വരെയാണ് നടന്നത്. സിങ്ക് സൾഫേറ്റ്, ബൊറാക്സ് എന്നിവ ഉപയോഗിച്ചുള്ള വിത്തുപചാരത്തിന്റെ സ്വാധീനം മനസിലാക്കുക, അതോടൊപ്പം തന്നെ ട്രൈക്കോഡെർമ വിരിഡേ ഉപയോഗിച്ചുള്ള വിത്തുപചാരം വൻപയറിന്റെ വളർച്ചയിലും വിളവിലും ചെലുത്തുന്ന സ്വാധീനം കണ്ടെത്തുക എന്നിവയായിരുന്നു പഠനത്തിന്റെ പ്രധാന ലക്ഷ്യങ്ങൾ.

ഗവേഷണത്തിന് പ്രധാനമായും രണ്ട് ഭാഗങ്ങൾ ഉണ്ടായിരുന്നു. ആദ്യ പരീക്ഷണത്തിൽ സിങ്ക് സൾഫേറ്റും ബൊറാക്സും വിവിധ അളവുകളിൽ വിത്ത് പൊതിയലും വിത്ത് പരിചരണവും ചെയ്തു. അവയിൽ നിന്ന്, ഏറ്റവും വേഗത്തിൽ മുളച്ചതും, കരുത്തേറിയ തൈകൾ ഉണ്ടായതുമായ ബൊറാക്സ് 50 മി.ഗ്രാം. ഒരു കി.ഗ്രാം വിത്ത് എന്ന് അളവിലും, 100 മി.ഗ്രാം ഒരു കി.ഗ്രാം വിത്ത് എന്ന അളവിലുമുള്ള രണ്ട് വിത്ത് പൊതിയൽ രീതികളും, സിങ്ക് സൾഫേറ്റ് 0.025 ശതമാനം ലായനിയിലും 0.05 ശതമാനം ലായനിയിലും 4 മണിക്കൂർ മുക്കി വച്ച് നടത്തുന്നതുമായ രണ്ട് വിത്ത് പരിചരണ രീതികളും തിരഞ്ഞെടുത്തു.

ആദ്യത്തെ പരീക്ഷണത്തിൽ നിന്ന് തിരഞ്ഞെടുത്ത നാല് വിത്തുപചാര രീതികളും അവയോടൊപ്പം ട്രൈക്കോഡെർമ വിരിഡേ ഒരു കി.ഗ്രാം വിത്തിന് 10 ഗ്രാം എന്ന രണ്ടാമത്തെ പരീക്ഷണത്തിന് ഉപയോഗിച്ചു. അതിനോടൊപ്പം തന്നെ, താരതമ്യ പഠനത്തിനായി വിത്തുപചാരം ചെയ്യാത്ത വിത്തിനെ ഉപയോഗിക്കുന്ന രീതിയും ഉൾപ്പെടുത്തി.

സിങ്ക് സൾഫേറ്റ് 0.05 ശതമാനം ലായനിയിൽ 4 മണിക്കൂർ വിത്ത് പരിചരണം ചെയ്ത പ്രയോഗത്തിലാണ് കൂടുതൽ ശാഖകളും, ഇലകളും, കായ്കളും, വിത്ത് മണികളും കാണപ്പെട്ടത്. പയർ വേരുകളിലെ റൈസോബിയം മുഴകൾ ഈ വിത്ത് പരിചരണ രീതിയിൽ കൂടുതലാണെന്നും കണ്ടെത്തി. സിങ്ക് സൾഫേറ്റ് 0.05 ശതമാനം ലായനി ഉപയോഗിച്ച് 4 മണിക്കൂർ വിത്ത് പരിചരണം നടത്തിയപ്പോൾ പയറിന്റെ വിളവ്, പോഷകങ്ങളുടെ ആഗിരണം, ആദായം, ലാഭം എന്നിവ കൂടുതലായി കണ്ടു.

വൻപയറിന്റെ വർദ്ധിത വിളവിന് വിത്തിനെ 0.05 ശതമാനം സിങ്ക് സൾഫേറ്റ് ലായനിയിൽ 4 മണിക്കൂർ മുക്കി വച്ച് വിത്ത് പരിചരണം ചെയ്യുന്നതാണ് നല്ലതെന്ന് കണ്ടെത്തി.