ALLELOPATHY FOR WEED MANAGEMENT IN FIELD CROPS

By

SHAKKIRA K. K.

(2019-11-238)

DEPARTMENT OF AGRONOMY

COLLEGE OF AGRICULTURE

VELLANIKKARA, THRISSUR - 680656

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THESIS

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DECLARATION

I, Shakkira K. K. (2019-11-238) hereby declare that the thesis entitled **"Allelopathy for weed management in field crops"** is a bona fide record of research work done by me during the course of research and the thesis has not been previously formed the basis for the award to me any degree, diploma, fellowship or other similar title, of any other university or society.

Vellanikkara

Date: 16.03.2022

Shakkira K. K.

(2019-11-238)

CERTIFICATE

Certified that the thesis entitled **"Allelopathy for weed management in field crops."** is a record of research work done independently by **Ms. Shakkira K. K.** (2019-11-238) under my guidance and supervision and thatit has not been previously formed the basis for the award of any degree, diploma, associate ship or fellowship to her.

Vellanikkara
Date : 16.03.2022

Dr. Sindhu P. V.
(Chairperson, Advisory committee)
Assistant Professor (Agronomy)
AICRP on MAP & B
College of Agriculture, Vellanikkara

CERTIFICATE

We, the undersigned members of the advisory committee of **Ms. Shakkira K. K.** (2019 -11- 238), a candidate for the degree of **Master of Science in Agriculture**, with major field in Agronomy, agree that this thesis entitled **"Allelopathy for weed management in field crops."** may be submitted by **Ms. Shakkira K. K.** (2019 -11- 238) in partial fulfilment of the requirement for the degree.

Dr. Sindhu P. V.
16.03.2022
(Chairperson, Advisory committee)
Assistant Professor (Agronomy)
AICRP on MAP&B
College of Agriculture, Vellanikkara

Dr. Prameela P.
16/3/22
(Member, Advisory Committee)
Professor and Head
Department of Agronomy
College Agriculture, Vellanikkara

16-03-22
Dr. Meera V. Menon
(Member, Advisory Committee)
Professor (Agronomy)
Cashew Research Station, Madakkathara

Dr. Beena C.
16/03/22
(Member, Advisory Committee)
Professor (Biochemistry)
AICRP on MAP&B
College of Agriculture, Vellanikkara

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And He is with you wherever you are *- Qur'an 57:4*

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

Introduction

1. INTRODUCTION

Sustainable crop production is one of the major challenges in today's agriculture where resources are limiting but demands for food grains are increasing. Both biotic and abiotic stresses are found almost equally responsible for losses in agricultural production and among biotic constraints, weeds pose the major problem in crop cultivation.

Among all the biotic stresses causing yield losses weeds alone account for 45 per cent of total annual crop yield loss in India, where as the contribution of insects, diseases and other pests are respectively 30 per cent, 20 per cent and 5 per cent (Rao, 2000). Looking at the global scenario, the main contributors of crop loss are again weeds, followed by animals and pathogens (Oerke, 2006). According to Indian Council of Agricultural Research (ICAR), India loses agricultural produce worth over $11 billion to weeds every year; it is more than the Centre’s budgetary allocation for agriculture for 2017-18. Weeds cause several issues in agro-ecosystems by competing for water, nutrients and sunlight, resulting in reduced crop yield and poor crop quality.

In light of these characteristics of weeds and their hazards, it becomes crucial to control them. There are several methods to control weeds such as physical, cultural, biological or chemical. Commonly used and quick method of weed management is the use of chemical measures through herbicide application. However, problems arise when there is over reliance on herbicides with similar modes of action resulting in the evolution of herbicide resistant weeds and a shift in weed flora towards difficult-to-control weeds (Chancellor, 1979). There were 255 herbicide resistant weed species, 148 dicot weeds and 107 monocot weeds were reported in 92 crops and 70 countries (Heap, 2018). Apart from this, ban on manufacture, sale and use of popular and currently marketed herbicides and global promotion of organic agriculture urges the need for alternative sustainable weed management strategies. The phenomenon of allelopathy has been suggested as a feasible non-chemical method towards this goal.

Allelopathic plants could be a source of new potential herbicidal molecules for the chemical industry, which has become necessary to overcome negative impacts of synthetic molecules. The term allelopathy generally refers to the stimulatory and inhibitory action of plants due to direct or indirect release of some chemical compounds (Rice, 1984). These plants synthesize and accumulate numerous components in the leaves, roots, fruits, flowers and bark with a good variety of allelochemicals including; phenolics, terpenoids, alkaloids and flavonoids (Rizvi and Rizvi, 1992).

Allelochemicals are liberated into the atmosphere in a variety of ways that involve; decomposition, volatilization, exudation and as leachates (Rice, 1984; Chase *et al*., 1991). Within the soil, allelochemicals have an effect on the event and growth of neighbouring plants in several ways including inhibition of germination and growth (Rizvi and Rizvi, 1992). However, the pattern of germination inhibition and also the suppression on earlier planted seedling growth has to be adequately studied.

Medicinal plants are considered as an important source of secondary metabolites having a number of biological functions. It has been reported that many medicinal plants species possess strong allelopathic potential and many researchers around the world are now showing earnest interest in medicinal plants for discovering new natural plant products (Qasem, 2002; Azizi and Fuji, 2006).

The present study entitled “Allelopathy for weed management in field crops” focused on assessing the allelopathic potential of the medicinal plants viz., bitter weed (*Andrographis paniculata*), indian borage (*Plectranthus ambonicus*) and southern cone marigold (*Tagetes minuta*) on the selected field crops of cowpea, green gram and rice, and also on weeds associated with them.

The specific objective of the study was:

- Assessment of allelopathic potential of selected plants for weed management in field crops

Review of literature

2. REVIEW OF LITERATURE

Weeds are the most important biotic constraint to agricultural production both in developing and developed countries. They are considered as the hidden stealers of nutrients, soil moisture and solar energy. There are different methods for controlling weeds such as physical, cultural, biological, or chemical. Nowadays, farmers mainly rely on chemical weed management, since it is cheap and most effective. However, with the increased adoption of organic farming and greater concerns on negative effects of herbicides, interest in non-chemical weed control methods has been growing in recent years. Allelopathy is one of the alternative strategies for non-chemical weed management. Allelopathic plants could be a source of new potential herbicidal molecules for the chemical industry, which have become necessary to overcome negative impacts of synthetic molecules. In this background, a brief review on allelopathy and its utilization in management of weeds in field crops is presented below. Reviews on weed problem in field crops are also briefed in this chapter.

2.1. Allelopathy

The term allelopathy in general, refers to the damaging effects of plants of one species on the germination, growth or development of plants of another species. The term allelopathy was coined by Molisch (1937) to refer to all chemically mediated interactions among plants (microbes and higher plants), either stimulatory or inhibitory. It includes interspecific as well as intraspecific chemical co-action (Bonner, 1950). The chemicals through which allelopathic effect is imposed are known as allelochemicals or allelochemics (Whittaker, 1970).

Allelopathy is defined as any direct or indirect harmful or beneficial effect by one plant (including microorganisms) on another through production of chemical compounds that escape into the environment (Rice, 1984). International Allelopathy Society (1996) defined allelopathy as any process involving secondary metabolites produced by plants, algae, bacteria and fungi that influence the growth and development of agricultural and biological systems excluding animals, with positive and negative effects.

A plant which produces allelochemicals is called the “donor plant,” while the plant affected by allelopathic compounds from the donor plant is called the “acceptor plant” (Muller, 1969).

Allelopathy can be employed as an alternative weed control strategy which is environmentally safe, conserves the available natural resources including water and mineral salts and also mitigates the problems raised by synthetic chemicals (Rizvi and Rizvi, 1992).

Allelopathy is introduced through crop rotations. Allelopathic crops are included in planned rotations, where their residual effect may suppress the weed flora and create a weed-free environment for the next crop. Weed growth inhibition is caused by the phytotoxic action of allelochemicals (Farooq *et al*., 2013).

The most sensitive stage of the target plant is always taken into account while exploiting allelopathy (Leather and Einhellig, 1986). According to Kil *et al*. (2002) inhibitory allelopathic effect of the plant is species specific and organ-specific. As per Bogatek *et al*. (2006), continuous release of allelochemicals increased weed growth inhibition. They reported complete failure of germination of mustard by the repeated application of sunflower extracts.

2.2. Allelochemicals

Allelochemicals are defined as ‘biocommunicators’, and may be produced by any part of plant viz., roots and leaves, pollen, seed or fruits, although the leaves and roots are the main sources (Horsley, 1977). Allelochemicals are secondary metabolites which are present in various plant species and are stored in roots, rhizomes, leaves, stems, pollen, seeds and flowers (Chon and Kim, 2002).

Quantitatively and qualitatively, production of allelochemicals depends on the stage of plant and is modified by environmental stresses like soil temperature, drought, flooding or poor drainage, sunlight, microorganisms, soil salinity, diseases, herbicides, minerals and even growth regulators or hormones. The effect of allelochemicals present

in the soil on crop plants is modified by factors such as soil moisture and soil temperature (Einhelling and Eckrich, 1984).

Some alkaloids, such as colchicine, vinblastine, and terpenoids, have been demonstrated to inhibit mitosis, and as a result, of plant development (Rice, 1974). Rizvi and Rizvi (1992) reported that alkaloids caused reduction in amylase activity of germinating seeds of *Amaranthus spinosa* there by limiting energy supply to the actively dividing embryonic cells. Phenolic compounds including salicylic acid and p-hydroxybenzoic acid have been reported to be very effective in controlling weeds (Duke *et al.,* 1997).

Phenolics, alkaloids, salicylates, brassinosteroids, terpenoids, hydroxamic acid, jasmonates, flavonoids and glucosinolates are some of the major secondary metabolites recognised as allelochemicals (Kruse *et al*., 2000; Jabran and Farooq, 2012).

Allelochemicals affected the rate at which ions were absorbed by plants (Rice, 1974). Phenolics have been shown to inhibit the absorption of ions and at the same time cause malformation of chlorophyll (Mersie and Singh, 1988).

Some allelochemicals have been reported to target photosystems and modify the electron carriers thus inhibiting the process of photosynthesis, while other chemicals inhibit respiration thereby reducing energy production (Rice, 1974). As per the reports of Barnes and Putnam (1986), allelochemicals were present both in weeds and crop plants and it affected different plant growth systems. However, the fate and actual modes of action of these compounds were not well understood and therefore recommended for further research on these compounds was recommended.

Allelochemicals can limit plant growth by creating an imbalance in phyto-hormones resulting in the poor establishment of seedlings. Aqueous extract from rice arrested barnyard grass by acting on the IAA (Lin *et al*., 2000).

Allelochemicals interfere with soil characteristics, add significant amount of phytotoxins during decomposition, decline the soil quality and reduce the crop growth and yield (Batish *et al*., 2006).

Allelochemicals have been shown to alter the membrane permeability of the root hair cells, reducing the rate of water absorption, conductivity and translocation of materials and thereby reducing shoot length (Ashrafi *et al.,* 2008).

A brief list of plant allelochemicals with herbicidal activity is presented below

Allelochemical	**Source**	**Mode of action**	**Reference**
Artemisinin	*Artimisia annua* L.	Peroxidase enzyme	Duke *et al*., 1987
Sorgoleone	*Sorghum bicolor*	PS II inhibition	Nimbal *et al*., 1996
1, 8- cineole	*Eucalyptus citriodora*	Mitosis	Romagni *et al*., 2000
DIMBOA	*Secale cereale*	Mitochondrial function	Burgos *et a*l., 2004
Momilactones	*Oryza sp.*	Unknown	Kato-Noguchi, 2004
Juglone	*Juglans nigra*	Mitochondrial respiration	Topal *et al*., 2007
Leptospermone	*Leptospermum scoparium*	p-hydroxy phenyl pyruvate dioxygenase	Dayan *et al*., 2011
Tricin	*Echinochloa colona*	Amylase activity and oxidative stress	Hegab *et al*., 2013
Tricolorin A	*Ipomoea tricolor*	Photosynthesis	Lotina-Hennsen *et al*., 2013
Sarmentine	*Piper spp.*	Membrane disruptor and PSII inhibitor	Dayan *et al*., 2015

2.3. Allelopathy for management of weeds by cultivation/cropping methods

Putnam and Duke (1974) reported the use of allelopathy in the management of weeds in many crops. Allelopathy can be employed as an alternative method for managing weeds without polluting the environment (Rizvi and Rizvi, 1992).The work done by Macias (1995) demonstrated that allelochemicals could be extracted from some plants and modified to bio-herbicides. According to Wu *et al.* (2001), allelopathic

properties of crop species could be considered as a supplement to other weed management strategies.

According to Teasdale and Mohler (2000), cover crops and their residues reduced the emergence of weeds in fields. Allelopathy overcame the challenges of resistance to synthetic herbicides in the field by weeds (Prather *et al.,* 2000). Cheema and Khaliq (2000) reported the use of sorghum straw soaked in water for 24 hours as herbicide against weeds in wheat. The method resulted in weed suppression of 35-49 per cent and yield increase of 10-12 per cent.

As per reports of Burgos *et al*. (2004) and Nagabushana *et al*. (2001), the cover crop residue on the soil surface contributed to weed suppression through the release of phytotoxins from decomposing residues.

An allelopathic crop designed in rotation sequences could suppress weeds in both cultivated and succeeding crops (Mamolos and Kalburtji, 2001) through residue decomposition or root exudates.

Study by Singh *et al.* (2003) demonstrated a number of crop plants with allelopathic potential that could be used as cover crops and as mulch to manage the weeds. In many cases, aqueous extract could be made from the allelopathic plants (Iqbal *et al*., 2007) and could be used for controlling weeds. They reported effective inhibition of purple nutsedge *(Cyperus rotundus* L.) density by about 70-90 per cent by intercropping single and double rows of sorghum, soybean and sesame in a cotton crop.

As per Uddin *et al*. (2014), wettable powder formulation of sorgoleone, a hydrophobic chemical found in *Sorghum bicolor* (L.) root exudates, was highly efficient in reducing weed development (20-25 %). According to them sorgoleone was more effective in controlling broadleaved weeds than grassy weeds.

Experiments were conducted by Mubeen *et al*. (2011) to study the germination and seedling growth response of rice (*Oryza sativa* L.) seeds soaked in distilled water to the aqueous extracts (1:20 w/v) of root, shoot, leaf, seed and whole plants of *Trianthema portulacastrum* L. The root extract of *T. portulacastrum* showed in

maximum mean germination time and time taken to 50 per cent germination of rice. Root and shoot length of rice were decreased when soaked in leaf extracts of *T. portulacastrum*.

Rye (*Secale cereal* L.) mulch considerably reduced the germination and growth of various troublesome grasses and broadleaved weeds (Schulz *et al*., 2013). Allelopathic measures, such as straw mulching, provided long-term weed control (Jabran *et al*., 2015), thus lowering the negative environmental impact of chemicals. Furthermore, straw mulch can promote soil fertility and raise soil organic matter content. Shokouhian *et al*. (2016) studied the effect of essential oils from some medicinal plants on seed germination of lettuce (*Lactuca sativa*), pepper (*Piper longum*) and tomato (*Solanum lycopersicum*) and reported their potential use as bioherbicides.

2.4. Allelopathic plants

Studies have been conducted to evaluate weed suppression effect of various plant species, including sorghum (Putnam *et al*., 1983); plants of Brassicaceae family (Haramoto and Gallandt, 2004); rye (Schulz *et al*., 2013) and sunflower (Alsaadawi *et al*., 2012).

During recent years, medicinal plants have been increasingly explored for their allelopathic potential (Anjum *et al*., 2010). Many workers evaluated the allelopathic potential of medicinal and aromatic plants (Fujii *et al*., 2003; Gilani *et al*., 2010; Nourimand *et al*., 2011). Owing to the richness of allelochemicals in *Tagetes minuta*, *Andrographis paniculata* and *Plectranthus ambonicus*, these plants may play a very important role in weed management through allelopathic interactions (Li *et al*., 2010; Sadia *et al*., 2015).

2.4.1. *Plectranthus ambonicus*

According to Grayer *et al*. (2010) flavonoids were the major compounds in 34 species of the genus *Plectranthus.* Khalid and El-Gohary (2014) reported that carvacrol and thymol represented the most abundant component of the oxygenated monoterpenes

in *Plectranthus amboinicus*. Swamy *et al*. (2017) reported the presence of phenolic and flavonoid compounds in the methanol extract of *Plectranthus ambonicus*. Presence of flavonoids and phenolics in *Plectranthus amboinicus* was also reported by El-Rokiek *et al*. (2018).

Allelopathic property of aqueous leaf extract of *Plectranthus* spp. on seed germination and seedling growth of *Bidens pilosa* and *Lactuca sativa* was reported by Azambuja *et al*. (2010). According to them allelopathic effect was directly proportional to the concentrations.

The essential oil from *Plectranthus ambonicus* and its chemotypes, carvacol and thymol, inhibited the germination and decreased root and aerial growth of *Latuca sativa* and *Sorghum bicolour* (Pinheiro *et al*., 2015). Allelopathic effects of *Plectranthus amboinicus* extracts on the growth of grass weed (*Phalaris minor*) and broad leaf weed (*Anagalis arvensis*) that grow with pea (*Pisum sativum*) were investigated by El-Rokiek *et al*. (2018), who reported that aqueous extract of *Plectranthus ambonicus* as most effective in controlling dicot weeds than monocots.

2.4.2. *Tagetes minuta*

Tagetes patula and *Tagetes minuta* possess a diversity of allelopathic compounds such as monocyclic and bicyclic monoterpenes, sesquiterpenes, flavonoids and thiophenes (Rodriquez and Mabry, 1977). Upon chemical characterization of *Tagetes minuta* Meshkadalsadat *et al*. (2010) observed the presence of 27 compounds that constituted 92 per cent of essential oil of aerial parts. As per Sadia *et al*. (2015) *Tagetes minuta* contains alkaloids, tannins, saponins, flavonoids and total phenolics, coumarins and catechins in different plant parts.

Arora *et al*. (2015) investigated the allelopathic potential of volatile oil of *Tagetes minuta* on other invasive weeds - *Chenopodium murale* L., *Phalaris minor* and *Amaranthus viridis* L. They reported that the volatile oil of *Tagetes minuta* significantly reduced the germination, growth, chlorophyll content and respiratory ability of recipient weeds in a dose dependent manner. Maximum reduction was observed in *Chenopodium murale* followed by *Phalaris minor* and least in *Amaranthus viridis*. The

response was concentration dependent. At lower quantities, germination was unaffected, but increased significantly as the concentration was increased.

Study conducted by Kil *et al*. (2002) showed reduction in seed germination and root hair growth of *Lotus comiculatus* var. *japonicus* by the aqueous extract of *Tagetes minuta* but not for *Lactuca sativa*. According to Batish *et al*. (2007) dried leaf powder of *Tagetes minuta* effectively controlled *Echinochloa crus-galli* and *Cyperus rotundus* of rice fields.

Due to the richness of allelochemicals, *Tagetes minuta* may play a very important role in weed management through allelopathic interactions. Phytochemical studies concluded that the allelochemicals present in leaves were more than that in root extracts (Alhammadi, 2008). He also reported inhibition in seed germination and seedling growth of *Acacia asak* by the use of *Tagetes minuta* extracts. Inhibition was more prominent with leaf extract than root extract.

Volatile oils extracted from some plant species had allelopathic potential to control weeds (Arora *et al*., 2015). They focussed on the potential utilization of volatile oil from *Tagetes minuta* to suppress the invasive weeds like *Chenopodium murale*, *Amaranthus viridis* and *Phalaris minor*.

Batish *et al*. (2007) investigated the potential herbicidal action of *Tagetes minuta* leaf powder (at 1, 2, and 4 t/ha) against two invasive rice weeds, *Echinochloa crus-galli* and *Cyperus rotundus*. It was concluded that when *Tagetes minuta* leaf powder was applied to rice fields, the emergence and growth of both weed species greatly reduced both under lab and field study.

2.4.3. *Andrographis paniculata*

Andrographis paniculata contains pharmaceutically important compounds such as diterpenoids, flavonoids, and polyphenols (Chao and Lin, 2010). The preliminary phytochemical analysis of *Andrographis paniculata* confirmed the presence of various secondary metabolites like steroids, alkaloids, phenols, catechin, flavonoids, saponins and tannins (Kalaivani *et al*., 2012).

Nagaraja and Deshmukh (2009) established the phytotoxic effect of *Andrographis paniculata* on the metabolic activities of *Parthenium hysterophorus*. They found that ground plant parts (leaves, stems, and roots) of *Andrographis paniculata* significantly inhibited the growth parameters such as height, leaf production and seeds per plantof *Parthenium hysterophorus*. The germination and growth of *Parthenium hysterophorus* was reduced by 25 per cent by the leaf and stem extracts, while 21.25 per cent reduction was noticed in root extract treatment.

Study conducted by Li *et al*. (2010) indicated that *Andrographis paniculata* had inhibitory effect on dicot plants. According to them, leaf water extract had more suppressing potential than root and stem extracts when applied on cabbage (*Brassica chinensis*), radish (*Raphanus sativus*), and *Desmodium styracifolium*.

Leaf extract of *Andrographis paniculata* reduced the growth of monocot weeds due to its effect on the reduction of sugar, non-reducing sugar, total sugar and soluble protein and stimulatory effect on total free amino acids (Mandal *et al*., 2016).

Kumar *et al*. (2018) reported the allelopathic property of *Andrographis paniculata*. They demonstrated the inhibitory effect of *Andrographis paniculata* on green gram (*Vigna radiata*) in laboratory condition.

2.5. Weed problems in field crops

Weeds are the major abiotic stress that hinder crop production and there by increase the yield loss. Knowledge about the intensity of weed flora and critical period of crop-weed competition are essential to control the weed infestation to a certain level in a successfully and economically viable way.

Cowpea, green gram and rice are the major field crops. According to Karim *et al*. (1998) production loss of 41.26 per cent in cereals, 40.82 per cent in oilseeds, 34.23 per cent in fibre crops, 33.16 per cent in food crops and 31.88 per cent in pulses were due to the weed competition. A yield loss of 10-100 per cent in rice and 10-45 per cent in green gram was reported by Gharde and Singh (2018).

Weeds, if left uncontrolled, can cause a yield reduction of 100 per cent. Weeds caused 2.7 million tons of grain loss at national level. In Indian agricultural production, weeds cost is over USD 11 billion each year. Weed-related yield losses in field crops were estimated to be 36 per cent in peanut (*Arachis hypogaea* L.), 31 per cent in soybean (*Glycine max* L.), 25 per cent in maize (*Zea mays* L.) and 19 per cent in wheat (*Triticum aestivum* L.) (Gharde *et al*., 2018).

According to Haefele *et al*. (2000) yield loss in irrigated rice due to weed infestation was 20 per cent. In transplanted rice uncontrolled weed growth caused 33-45 per cent reduction in grain yield (Singh *et al*., 2007; Manhas *et al.,* 2012). Hosoya and Sugiyama (2016) found that two dominant weed species, including *Monochoria vaginalis* and *Cyperus* spp. accounted for 84 per cent of the total weed biomass in the rice field. Gharde *et al*. (2018) reported that economic loss due to weeds alone was about 21.4 per cent for direct seeded and 13.8 per cent in transplanted rice.

Wet seeded rice was infested with composite weed flora comprising of grasses, broad leaved weeds and sedges, the majority of which were grasses (Singh *et al*., 2007; Ravisankar *et al*., 2008). In lowland rice weeds caused yield loss of 15 to 76 per cent and removed 21-42 kg N, 10-13.5 kg P and 17-27 kg K/ha (Duary *et al.,* 2015).

Cowpea is one of the most important grain legumes in many tropical countries. Cowpea suffers weed problem at early stages of growth and development before the establishment of well-developed canopy and ground cover (Osipitan *et al.,* 2016). Weeds alone contribute to cowpea yield loss as high as 76 per cent depending on the cultivar, environment and weed management practices (Osipitan *et al.,* 2016).

Weed competition is most critical during the first 14 to 40 days of cowpea growth (Medrano *et al*., 1973). Season-long hindering effect of weeds could potentially reduce the cowpea grain yield about 53 to 76 per cent (Olorunmaiye and Ogunfolabi, 2002). Delaying of weed removal up to 14 days after emergence resulted in yield loss of 4-15 per cent (Adigun *et al*., 2014).

Tripathi and Singh (2001) reported that *Dactyloctenium aegyptium* (41.8 %), *Eleusine indica* (15.7 %), *Gnaphalium indicum* (14.4 %), *Cyperus rotundus* (12.8 %),

Echinochloa crus-galli (8.4 %) and *Sorghum halepense* (6.9 %) as the major weed flora infesting cowpea. According to them, these weeds reduced yield by up to 82 per cent. Freitas *et al*. (2009) reported that weed competition in cowpea reduced the number of pods per plant and thereby reduced yield by up to 90 per cent.

Green gram yield loss is more pronounced due to the infestation of weed flora of various classes like broad leaved weeds, grasses and sedges. Among the different classes, species belonging to broad leaved weeds caused maximum yield reduction in green gram (60 per cent) followed by grasses (42 per cent) and sedges (6 per cent) (Sangakkara *et al.,* 1995).

Punia *et al.* (2013) reported 22 weed species responsible for growth and yield reduction in green gram. According to them 14 broad leaved weeds, five grasses and three sedges were the dominant weed flora. Among these weeds, *Digera muricata* was the most dominant broad leaved weed accounting for 49.53 per cent relative density, whereas *Dactyloctenium aegyptium* (11.84 %) and *Echinochloa colona* (9.65 %) were the dominant grasses.

Delay in weeding up to 42 days after sowing resulted in greater weed biomass and subsequently decreased the seed yield of green gram (Enyi, 1973). Seed yield reduction by weed infestation could be as high as 25.7 per cent whereas 19.1 per cent and 16.3 per cent loss was observed from infestation by insects and diseases respectively (Karmakar *et al*., 2015).

Materials and methods

3. MATERIALS AND METHODS

The research work entitled "Allelopathy for weed management in field crops" was conducted during February-October 2021 in the Department of Agronomy, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur. The study consisted of two parts, viz., screening *Andrographis paniculata*, *Plectranthus ambonicus* and *Tagetes minuta* for their allelopathic potential and evaluating allelopathic effect of these plants extracts on weeds and the test crops of rice, cowpea and green gram. The materials used and methodology adopted for this study are described in this chapter.

3.1. General details

Location

Screening of selected plants for their allelopathic potential and pot culture study to assess the allelopathic effect of plant extracts on weeds and test crops were conducted inside the green house attached to the field laboratory of AICRP on Weed Control. The site was situated at $10^0$32'58" N latitude and $76^0$17'00" E longitude with an altitude of 40.3 m above mean sea level. Lab study for assessing allelopathic effect of plant extracts on weeds and test crops was carried out in the laboratory of the Department of Agronomy, College of Agriculture, Vellanikkara, Thrissur.

Soil

Soil for conducting screening experiment and pot culture study was collected from the Agronomy Crop Museum, College of Agriculture, Vellanikkara, Thrissur. The land from which the soil was collected had been under cultivation with Chinese potato (*Solenostemon rotundifolius*) during previous years. The texture of the experimental soil was sandy clay loam and was acidic in reaction with a pH of 4.74. The physical and chemical properties of soil and methods used for its analysis are depicted in Table 1.

Table 1. Physical and chemical properties of soil taken for experiment

Particulars	Value	Method adopted
1. Physical properties (Particle size composition)		
Coarse sand (%)	31.90	Robinson international pipette method (Piper, 1942)
Fine sand (%)	27.30	
Silt (%)	18.64	
Clay (%)	22.16	
2. Chemical properties		
pH	4.74	1: 2.5 soil water suspension (Jackson, 1958)
Organic carbon (%)	0.76 (Medium)	Walkley and Black method (Jackson, 1958)
Available N (kg/ha)	124 (Low)	Alkaline Permanganate Method (Subbaiah and Asija, 1956)
Available P_2O_5 (kg/ha)	66 (High)	Ascorbic acid reduced molybdo phosphoric acid blue colour method (Bray and Kurtz, 1945; Watanabe and Olsen, 1965)
Available K_2O (kg/ha)	218.16 (Medium)	Neutral normal ammonium acetate extraction and estimation using flame photometry (Jackson, 1958)

Allelopathic plants and test crops

Allelopathic plants : 1. *Andrographis paniculata* (Bitter weed)

2. *Plectranthus ambonicus* (Indian borage)

3. *Tagetes minuta* (Southern cone marigold)

Test crops : 1. *Oryza sativa* (Rice)

2. *Vigna unguiculata* (Cowpea)

3. *Vigna radiata* (Green gram)

3.2. Experimental details

3.2.1. Screening of selected plants for allelopathic potential against weeds

Experiment for screening selected plants for allelopathic potential against weeds was carried out in the green house attached to field laboratory of the AICRP on Weed Control, College of Agriculture, Vellanikkara. The plants *Plectranthus ambonicus, Andrographis paniculata* and *Tagetes minuta* were screened for their allelopathic potential against upland weeds in plastic trays (25 cm x 20 cm x 5 cm). The experiment was carried out by following completely randomized design (CRD) in factorial arrangement with three replications.

The allelopathic effect of donor plants on weeds was studied using 165 plastic trays that were filled to three-quarters with uniform quantity of soil (1.5 kg) collected from an open area. After collection, soil was sieved to remove pebbles and stones. The trays were then separated into three groups of 54 trays for screening the donor plants *Plectranthus ambonicus, Andrographis paniculata* and *Tagetes minuta* and 3 trays with sterilised soil with distilled water as control treatment. Within total (162 trays), the trays were grouped into three sets of 3 trays based on the method of extraction; cold water, hot water and methanol extraction. Within each method of extraction, three sets of 6 trays were randomly assigned based on concentration to each tray 5%, 10%, 15%, 20%, 25% and 30% from three donor plants. Trays with distilled water and sterilised soil were taken as control treatment.

The quantity of water required for reaching field capacity was tested before treatment application and calculated as 350 ml for each tray. Based on the field capacity,

extracts were prepared in appropriate quantity for each concentration for three replications. The treatments were imposed to investigate the allelopathic effect of selected plants on weed germination and growth. The effect was studied on the weed seeds already present in the soil naturally and no sowing was done.

Quantity of plant sample required to prepare each concentration are calculated and given in the Table 2.

Table 2. Quantity of plant sample (crushed weight) for each concentration

Concentration	Quantity of plant sample/tray (g/350 ml)
5 %	17.5
10 %	35.0
15 %	52.5
20 %	70.0
25 %	87.5
30 %	105.0

Technical programme

Design : CRD (Factorial)

Number of replications : 3

Treatment combinations : (3 x 3 x 6) + 1

Treatments

Treatment details are furnished in Table 3.

Factor A : Allelopathic plants

1. *Andrographis paniculata*

2. *Plectranthus ambonicus*

3. *Tagetes minuta*

Factor B : Medium for extraction

1. Cold water extract

2. Hot water extract

3. Methanol extract

Factor C : Concentration

1. 5 %

2. 10 %

3. 15 %

4. 20 %

5. 25 %

6. 30 %

And sterilised soil with distilled water as control treatment.

Table 3. Treatment details

Notations	Treatments
T_1	Cold water extract of *Andrographis paniculata* @ 5 %
T_2	Cold water extract of *Andrographis paniculata* @ 10 %
T_3	Cold water extract of *Andrographis paniculata* @ 15 %
T_4	Cold water extract of *Andrographis paniculata* @ 20 %
T_5	Cold water extract of *Andrographis paniculata* @ 25 %
T_6	Cold water extract of *Andrographis paniculata* @ 30 %
T_7	Hot water extract of *Andrographis paniculata* @ 5 %
T_8	Hot water extract of *Andrographis paniculata* @ 10 %
T_9	Hot water extract of *Andrographis paniculata* @ 15 %
T_{10}	Hot water extract of *Andrographis paniculata* @ 20 %
T_{11}	Hot water extract of *Andrographis paniculata* @25 %
T_{12}	Hot water extract of *Andrographis paniculata* @ 30 %
T_{13}	Methanol extract of *Andrographis paniculata* @ 5 %
T_{14}	Methanol extract of *Andrographis paniculata* @ 10 %
T_{15}	Methanol extract of *Andrographis paniculata* @ 15 %
T_{16}	Methanol extract of *Andrographis paniculata* @ 20 %
T_{17}	Methanol extract of *Andrographis paniculata* @ 25 %
T_{18}	Methanol extract of *Andrographis paniculata* @ 30 %
T_{19}	Cold water extract of *Plectranthus ambonicus* @ 5 %
T_{20}	Cold water extract of *Plectranthus ambonicus* @ 10 %
T_{21}	Cold water extract of *Plectranthus ambonicus* @ 15 %
T_{22}	Cold water extract of *Plectranthus ambonicus* @ 20 %

T_{23}	Cold water extract of *Plectranthus ambonicus* @ 25 %
T_{24}	Cold water extract of *Plectranthus ambonicus* @ 30 %
T_{25}	Hot water extract of *Plectranthus ambonicus* @ 5 %
T_{26}	Hot water extract of *Plectranthus ambonicus* @ 10 %
T_{27}	Hot water extract of *Plectranthus ambonicus* @ 15 %
T_{28}	Hot water extract of *Plectranthus ambonicus* @ 20 %
T_{29}	Hot water extract of *Plectranthus ambonicus* @ 25 %
T_{30}	Hot water extract of *Plectranthus ambonicus* @ 30 %
T_{31}	Methanol extract of *Plectranthus ambonicus* @ 5 %
T_{32}	Methanol extract of *Plectranthus ambonicus* @ 10 %
T_{33}	Methanol extract of *Plectranthus ambonicus* @ 15 %
T_{34}	Methanol extract of *Plectranthus ambonicus* @ 20 %
T_{35}	Methanol extract of *Plectranthus ambonicus* @ 25 %
T_{36}	Methanol extract of *Plectranthus ambonicus* @ 30 %
T_{37}	Cold water extract of *Tagetes minuta* @ 5 %
T_{38}	Cold water extract of *Tagetes minuta* @ 10 %
T_{39}	Cold water extract of *Tagetes minuta* @ 15 %
T_{40}	Cold water extract of *Tagetes minuta* @ 20 %
T_{41}	Cold water extract of *Tagetes minuta* @ 25 %
T_{42}	Cold water extract of *Tagetes minuta* @ 30 %
T_{43}	Hot water extract of *Tagetes minuta* @ 5 %
T_{44}	Hot water extract of *Tagetes minuta* @ 10 %
T_{45}	Hot water extract of *Tagetes minuta* @ 15 %
T_{46}	Hot water extract of *Tagetes minuta* @ 20 %
T_{47}	Hot water extract of *Tagetes minuta* @ 25 %
T_{48}	Hot water extract of *Tagetes minuta* @ 30 %
T_{49}	Methanol extract of *Tagetes minuta* @ 5 %
T_{50}	Methanol extract of *Tagetes minuta* @ 10 %
T_{51}	Methanol extract of *Tagetes minuta* @ 15 %
T_{52}	Methanol extract of *Tagetes minuta* @ 20 %
T_{53}	Methanol extract of *Tagetes minuta* @ 25 %
T_{54}	Methanol extract of *Tagetes minuta* @ 30 %
T_{55}	Control (distilled water)

The treatments were applied uniformly to the plastic trays immediately after filling trays with upland soil. Only a single application of treatments was given. Trays were irrigated at two days interval starting from 3rd day after treatment application in order to maintain trays at field capacity. Trays were examined daily for germination and kept for one month for recording observations on weed growth parameters.

Preparation of plant extracts

Source of plants

Seeds of *Andrographis paniculata* and *Plectranthus ambonicus* were collected from AICRP on MAP&B, COA, Vellanikkara. *Tagetes minuta* seeds obtained from the Department of Floriculture, COA, Vellanikkara were grown in the Agronomy Crop Museum and collected for extraction.

Aqueous extract

For preparing aqueous extract, whole plant of 5 kg of each were collected and washed to remove the adhering soil. Cleaned samples were macerated and 5 L of distilled water was added. These samples were shaken for 5 hours continuously in an electric shaker and the mixture was filtered through Whatman No. 1 filter paper to get the extract having concentration of 100 % w/v were used as stock solution. These extracts were diluted to desired concentrations of 5 %, 10 %, 15 %, 20 %, 25 % and 30 % using distilled water.

Hot water extract

Fresh and clean whole plant samples weighing 5 kg were crushed and transferred into a beaker containing 5 L distilled water and boiled for five minutes followed by shaking for 5 hours. The room cooled extract was filtered through Whatman No. 1 filter paper and the filtrate having 100 % concentration in w/v was used as stock solution. From this stock, desired concentrations of 5 %, 10%, 15 %, 20 %, 25 % and 30 %were made using distilled water.

Methanol extract

Methanol extracts were prepared by soaking 5 kg crushed whole plant samples in analytical grade methanol of 5 L and boiled for five minutes followed by shaking in an electronic shaker for 5 hours at room temperature. The extracts were filtered through Whatman No. 1 filter paper and kept for methanol to evaporate to dryness and residues were collected. The residues collected were dissolved in 5L of distilled water to obtain the stock of 100 % w/v. Desired concentrations of 5 %, 10 %, 15 %, 20 %, 25 % and 30 % were prepared by adding distilled water.

Observations

Observations on weeds

Germination count at weekly intervals

The number of weed seeds germinated was counted at weekly intervals up to one month of treatment application.

Density of weeds at one month after application

Germinated weeds from tray were uprooted after one month and categorized into grasses and broad leaved weeds and expressed in no./m^2.

Dry weight of weeds at one month after application

One month after treatment application, all the germinated weeds were uprooted from the plastic trays, cleaned and oven dried at 80 ± 5°C. Weed dry weight was recorded and expressed in g/m^2.

Biochemical analysis of extracts

Biochemical parameters like pH, EC, total alkaloids, flavonoids, phenols and tannins of different extracts from the allelopathic plants were estimated and the data are presented in the Table 4.

pH and EC of different extracts were measured using pH meter and electrical conductivity meter. Other parameters like total alkaloids, flavonoids, phenols and tannins were determined using the standard analytical methods (Harborne, 1973).

Total alkaloid content

A sample of 5 ml was poured into a 250 ml conical flask and 200 ml of 10% acetic acid in ethanol was added, covered and then allowed to stand for four hours. This extract was filtered and concentrated to one fourth of the original volume by keeping on water bath. To this, concentrated ammonium hydroxide was added drop wise until the precipitation of extract was completed. The whole extract was kept to settle and precipitate was collected and washed with diluted ammonium hydroxide and then filtered. The residue obtained in the filter paper was dried and weighed and expressed as percentage.

Total flavonoid

Total flavonoid content was estimated by Aluminium chloride colorimetric method with catechin (flavon-3-ol catechin) as standard. An aliquot of 0.5 ml sample was taken in a test tube containing 2 ml of distilled water. To this, 0.15 ml of 5 % $NaNO_2$ and 0.15 ml of 10 % $AlCl_3$ were added. After keeping for five minutes, 2 ml of 4 % NaOH and 0.2 ml of distilled water were added and mixed well, and kept for 15 minutes to develop a brown red colour. The absorbance was read in spectrophotometer at 510 nm. A standard solution of catechin was prepared with a concentration of 1 mg/ml and subjected to same process as that of sample. Absorbance was read at 510 nm.

Calculation was made by using the following formula and consolidating the weight of sample and volume made up. Total flavonoid content was expressed as percentage.

$$\text{Concentration of flavonoids in sample (mg/ml)} = \frac{\text{Reading of test X Concentration of standard}}{\text{Reading of standard}}$$

Total phenols

Total phenolic content was determined using Folin-Ciocalteau reagent with catechol as standard. One ml of the extract was taken in a test tube and mixed with 2 ml distilled water. Then 0.5 ml of Folin and Ciocalteu's phenol reagent were added and incubated for 3 minutes at room temperature. To this 2 ml of saturated sodium bicarbonate (20 %) was added. The reaction mixtures were kept for boiling in water bath for 1 minute, so that a blue colour was developed. Tubes were taken out and cooled under tap water. The absorbance was read in spectrophotometer at 650 nm. A standard solution with catechol 0.1 mg/ml was prepared and process as sample. Absorbance was read at 650 nm. Weight of sample taken and volume made up was also considered and total phenol concentration was calculated using the formula.

$$\text{Concentration of phenol in sample (mg/ml)} = \frac{\text{Reading of test X Concentration of standard}}{\text{Reading of standard}}$$

Total tannins

Tannin content was estimated by Folin-Denis method using tannic acid solution (0.5 mg/ml) as standard. Five ml of extract as well as standard were taken separately and mixed with 5 ml of Folin- Denis reagent and 10 ml of Na_2CO_3. Then the volume was made up to 100 ml by adding 80 ml of distilled water and mixed well and kept for 30 minutes. The blue colour developed was read in spectrophotometer at 700 nm and concentration was calculated using the formula and also considering the weight of sample and volume made up.

$$\text{Concentration of tannin in sample (mg/ml)} = \frac{\text{Reading of test X concentration of standard}}{\text{Reading of standard}}$$

Table 4: Biochemical properties of extracts

Plants	Methods of extraction	pH	EC ($dS^{-1}m$)	Alkaloids (%)	Flavonoids (%)	Phenols (%)	Tannins (%)
A. paniculata	Cold water	6.53	0.32	0.541	0.023	0.001	0.0007
	Hot water	7.62	0.46	0.149	0.020	0.001	0.0009
	Methanol	5.82	0.43	0.562	0.026	0.002	0.0006
P. ambonicus	Cold water	6.19	0.47	0.154	0.037	0.004	0.0002
	Hot water	6.70	0.49	0.156	0.027	0.003	0.0002
	Methanol	4.47	0.42	0.237	0.053	0.006	0.0003
T. minuta	Cold water	6.18	0.21	0.386	0.030	0.003	0.0005
	Hot water	7.03	0.49	0.218	0.024	0.003	0.0001
	Methanol	4.3	0.32	0.851	0.040	0.004	0.0007

3.2.2. Allelopathic effect of plant extracts on weeds and test crops

3.2.2.1 : Lab study

Experimental details

The experiment was conducted in completely randomized design (CRD) with three replications. Rice, cowpea and green gram were the test crops. Seeds of test crops were procured from Department of Agronomy, COA, Vellanikkara.

Uniform number of seeds (4 seeds/petri plate and 3 petri plates/replication) of test crops was dibbled in petri plate lined with filter paper and best 10 treatments from first experiment were imposed (Table 5). Before the treatment application field capacity of filter paper used was calculated and noted as 1 ml.

Technical programme

Design : CRD (Factorial)

Number of replications : 3

Test crops : Rice, cowpea and green gram

Treatments

Factor A : Time of application

1. On the day of sowing
2. 6th day after sowing

Factor B

Best 10 treatment combinations from experiment 1 and a control with distilled water.

Table 5: Treatment details

Notations	Treatments
T_1	Cold water extract of *Andrographis paniculata* @ 25 %
T_2	Cold water extract of *Andrographis paniculata* @ 30 %
T_3	Methanol extract of *Andrographis paniculata* @ 25 %
T_4	Methanol extract of *Andrographis paniculata* @ 30 %
T_5	Cold water extract of *Tagetes minuta* @ 25 %
T_6	Cold water extract of *Tagetes minuta* @ 30 %
T_7	Hot water extract of *Tagetes minuta* @ 25 %
T_8	Hot water extract of *Tagetes minuta* @ 30 %
T_9	Methanol extract of *Tagetes minuta* @ 25 %
T_{10}	Methanol extract of *Tagetes minuta* @ 30 %
T_{11}	Control (distilled water)

Two groups of petri plates with 11 treatments, three replications and three plates per replication (99 plates for one group) were maintained. In the first group treatments were applied on the same day of sowing and in the second group treatment application was done on 6th day of sowing. Distilled water was applied uniformly on alternate days for keeping petri plate moistened. Trays were examined daily for germination and kept for 15 days for taking observations on growth parameters.

Observations

Observations on test crops

Days to first germination

The germination of test crops in the petri plates was observed daily and the days to delay in germination of seeds due to the treatment application as compared to control was noted.

Germination count

Number of seeds germinated was counted daily continuously for 15 days.

Shoot length at 15 days after spraying

Shoot length of germinated seeds were measured in cm from the point where root and shoot joined together to the top of shoot.

Root length at 15 days after spraying

Root length of the seedlings was measured in cm from the point where root and shoot joined together to the end of root.

Fresh weight of seedlings at 15 days after spraying

Seedlings were taken from petri plate and the fresh weight in milligram was recorded.

Speed of germination

Speed of germination was calculated as per formula of Allan *et al*. (1962) and expressed as numbers per day.

Speed of germination: S = N1 / T1+ N2 / T2+ N3 / T3+……+ Nk / Tk;

Where, N1, N2, N3, ……, Nk are the number of seeds germinated at T1, T2, T3,……, Tk days after sowing.

3.2.2.2 : Pot culture study

The experiment was carried out in the greenhouse attached to field laboratory of AICRP on Weed Control, using pots of 21 cm x17 cm x11 cm dimension. Soil collected from an open area was sieved to remove stones and pebbles and pre-heated at a temperature of 105°C for 5 minutes in the oven. Then the pots were filled with uniform quantity of soil (3 kg/pot). The quantity of water required to attain field capacity was estimated before treatment application and was observed to be 700 ml for

3 kg soil. The experiment was carried out in completely randomized design (CRD) with three replications. The test crops used were cowpea, green gram and rice.

Quantity of plant sample required to prepare each concentration are calculated and given in the Table 6.

Table 6. Quantity of plant sample (crushed weight) for each concentration

Concentration	Quantity of plant sample/tray (g/700 ml)
25 %	175
30 %	210

Seeds of selected test crops were dibbled @ 4 seeds per pot. Two sets of pots with 33 pots in each group were maintained. In one group treatments were imposed on the day of sowing and in second group at six days after sowing. Crops and weeds were examined daily to record phytotoxicity symptoms on seedlings. Treatment details are given in Table 7.

Table 7. Treatment details

Notations	Treatments
T_1	Cold water extract of *Andrographis paniculata* @ 25 %
T_2	Cold water extract of *Andrographis paniculata* @ 30 %
T_3	Methanol extract of *A. paniculata* @ 25 %
T_4	Methanol extract of *A. paniculata* @ 30 %
T_5	Cold water extract of *Tagetes minuta* @ 25 %
T_6	Cold water extract of *Tagetes minuta* @ 30 %
T_7	Hot water extract of *Tagetes minuta* @ 25 %
T_8	Hot water extract of *Tagetes minuta* @ 30 %
T_9	Methanol extract of *Tagetes minuta* @ 25 %
T_{10}	Methanol extract of *Tagetes minuta* @ 30 %
T_{11}	Control (distilled water)

Observations

Observations on weeds

Weed count at 3, 6, 12 and 25 days after sowing

Weed seeds germinated were counted at 3rd, 6th, 12th and 25th days after the application of treatments.

Weed density at month after application

Weeds grown in the tray were uprooted, counted and categorized into grasses and broad leaf weeds at one month after application. The wee density was expressed in nos./m^2.

Weed dry weight at 3, 6, 12 and 25 days after sowing

Germinated weeds were uprooted from the pot at 3rd, 6th, 12th and 25th days after spraying. After cleaning they were air dried and then oven dried at 80 ± 5°C. The weed dry weight was recorded in grams and expressed as g/m^2.

Observations on crops

Germination count at weekly interval

The sprouted seedlings were counted at weekly intervals till 30 days after treatment application.

Visual symptoms of phytotoxicity

Seedlings were examined for the presence of phytotoxicity symptoms.

Shoot length at one month after sowing

Sprouted seedlings from the pots were uprooted and the shoot length in cm from the point where root and shoot joined together to the top of shoot was measured.

Root length at one month after sowing

Germinated crop seeds were uprooted from pot and recorded the root length in cm from the point where root and shoot joins together to the end of root.

Fresh weight of seedlings at one month after sowing

Seedlings were uprooted after one month and fresh weight was recorded and expressed in grams.

Dry weight of seedlings at one month after sowing

All the sprouted seedlings were shade dried and then oven dried till constant weight. The dried weight was recorded and expressed in gram.

3.3. Statistical analysis

The data were analyzed statistically using analysis of variance (ANOVA) with statistical package 'OP Stat' (Sheoran *et al*., 1998). The data on weed count which showed wide variation were subjected to square root transformation to make the analysis of variance valid (Gomez and Gomez, 1984).

Plate. 1 Experimental set up of screening of allelopathic plants for allelopathic potential against weeds

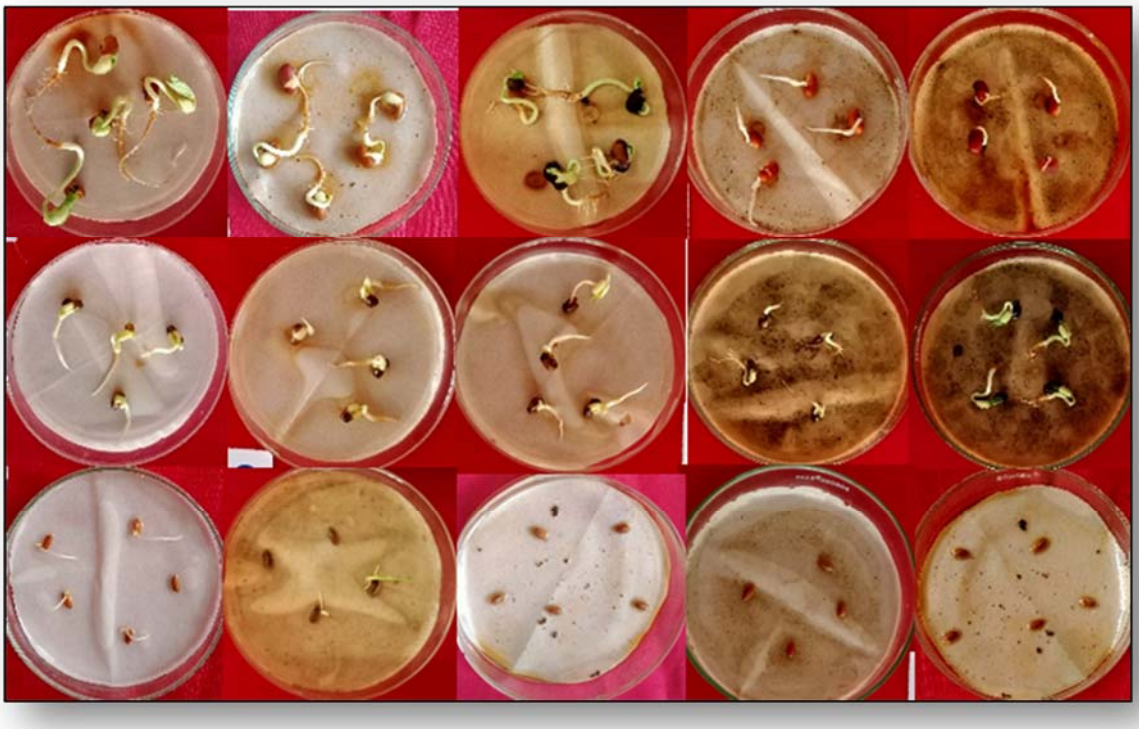


Plate. 2 Experimental set up of petri plate study

Plate. 3 Experimental set up of pot culture study

Results

4. RESULTS

4.1. Experiment 1. Screening of selected plants for allelopathic potential against weeds

4.1.1. Direct effects of treatments

4.1.1.1. Observation on weeds

Germination count of weeds at weekly intervals

Number of weeds germinated in the trays was counted at weekly intervals (Table 8) up to one month of treatment application and it showed significant effect during first week. During first week, the lowest germination count was observed in treatment with *Tagetes minuta* (72.38 no./m^2) followed by *Andrographis paniculata* (86.48 no./m^2). Trays sprayed with *Plectranthus ambonicus* recorded the highest germination count of weeds (154.92 no./m^2). During subsequent weeks of observations direct effect of allelopathic plants on weed germination was not statistically significant.

Method of extraction exhibited significant influence on germination count in the 1st week. Among the different methods of extraction, the lowest germination count (92.06 no./m^2) was observed in methanol extraction followed by cold water extraction (103.02 no./m^2). Hot water extraction recorded higher (114.52 no./m^2) weed count than the other two methods of extraction. Method of extraction did not exhibit significant influence on weed count during subsequent stages of observation.

Effect of concentration of extract on germination count of weeds was significant during 1st and 2nd weeks after application. During 1st week of observation, the lowest weed count (67.22 no./m^2) was recorded in 30 per cent followed by 25 per cent (82.04 no./m^2), 20 per cent (89.81 no./m^2), 15 per cent (96.11 no./m^2), 10 per cent (105.93 no./m^2) and 5 per cent (112.96 no./m^2) respectively. The higher weed count (168.33 no./m^2) was observed in control treatment. During 2nd week, maximum reduction (123.33 no./m^2) in weed count was found in 30 per cent concentration which was on par with 25 per cent concentration (126.11 no./m^2). All other concentrations were on par with each other and also with the control treatment.

Table 8. Direct effect of treatments on total weed count at weekly intervals

Treatments	Total weed count (No./m^2)			
	1st week	2nd week	3rd week	4th week
Plants				
Andrographis paniculata	8.74 (86.48)	11.46 (130.56)	7.46 (55.63)	3.51 (12.31)
Plectranthus ambonicus	12.44 (154.92)	11.49 (131.43)	7.50 (56.27)	3.47 (12.06)
Tagetes minuta	8.04 (72.38)	11.58 (134.21)	7.33 (53.81)	3.47 (12.05)
CD (0.05)	0.21	NS	NS	NS
Method of extraction				
Cold water extract	9.78 (103.02)	11.52 (132.70)	7.35 (54.21)	3.51 (12.35)
Hot water extract	10.48 (114.52)	11.52 (132.78)	7.33 (53.73)	3.51 (12.30)
Methanol extract	8.95 (92.06)	11.43 (130.71)	7.60 (57.78)	3.43 (11.78)
CD (0.05)	0.21	NS	NS	NS
Concentration of extract				
5%	10.49 (112.96)	11.58 (134.26)	7.37 (54.26)	3.45 (11.89)
10%	10.11 (105.93)	11.61 (135.37)	7.29 (53.15)	3.45 (11.89)
15%	9.55 (96.11)	11.68 (137.22)	7.34 (53.89)	3.42 (11.70)
20%	9.20 (89.81)	11.65 (136.48)	7.39 (54.63)	3.51 (12.33)
25%	8.66 (82.04)	11.22 (126.11)	7.60 (57.78)	3.37 (11.33)
30%	7.19 (67.22)	11.09 (123.33)	7.72 (59.63)	3.54 (12.52)
Control	12.98 (168.33)	11.47 (131.67)	7.30 (53.33)	3.65 (13.33)
CD (0.05)	0.32	0.39	NS	NS

** $\sqrt{x+0.5}$ transformed values, original values are given in parentheses

Density of weeds at one month after treatment application

The data on the direct effect of treatments on density of grasses, broad leaved weeds and total weeds are furnished in Table 9. Direct effect of three treatment factors on suppressing the density of grasses was not significant. However, density of broad leaved weeds and total weeds reduced significantly due to the influence of allelopathic plants, method of extraction and concentration of extracts.

Tagetes minuta exhibited the highest inhibitory effect on weed density of broad leaved weeds (179.14 no./m^2) followed by *Andrographis paniculata* (186.21 no./m^2). The highest density of broadleaved weeds was observed in trays treated with *Plectranthus ambonicus* (260.36 no./m^2). With respect to total weed density, *Tagetes minuta* was the most effective plant (273.23 no./m^2). It on par with *Andrographis paniculata* (280.81 no./m^2). The highest total weed density was noticed in treatment with *Plectranthus ambonicus* (354.18 no./m^2).

The data on direct effect of method of extraction revealed significant inhibitory effect on germination of broad leaved and total weeds, but not on grass weeds. The lowest density of broad leaved weeds (198.17 no./m^2) and total weeds (291.88 no./m^2) were recorded with methanol extraction, followed by cold water extraction which had broad leaved weed density of 208.14 no./m^2 and total weed density of 302.58 no./m^2. The highest density of weeds was recorded in hot water extraction with 219.89 no./m^2 of broad leaved weeds and 313.65 no./m^2 of total weeds.

There was no significant difference in density of grass weeds due to concentration of extracts. Higher concentration of 30 per cent had recorded significantly the lowest weed density (168.33 nos./m^2) of broad leaved weeds followed by 25 per cent (183.70 no./m^2). Total weed density was lowest in 30 per cent and 25 per cent concentrations (262.70 no./m^2 and 277.26 no./m^2 respectively). The control treatment recorded the highest weed density of broad leaved weeds (271.67 no./m^2) and total weeds (366.67 no./m^2).

Weed dry weight at one month after treatment application

The data on direct effect of treatments on weed dry weight at one month after application are presented in Table 9. Effect on dry weight of grass weeds was non-significant for all three factors studied.

Allelopathic effect by the extract, *Tagetes minuta*, caused the highest reduction in the dry weight of broad leaved weeds (37.16 g/m^2) and total weeds (42.13 g/m^2) followed by *Andrographis paniculata,* which recorded broad leaved weed dry weight of 39.50 g/m^2 and total weed dry weight of 44.55 g/m^2. *Plectranthus ambonicus* recorded the highest dry weight (44.56 g/m^2) of broad leaved weeds and also total weed dry weight (49.62 g/m^2).

Regarding method of extraction, significantly lower broad leaved weed dry weight (37.40 g/m^2) was found in methanol extraction and was on par with cold water extraction (39.73 g/m^2). The highest dry weight was in hot water extraction (43.33 g/m^2). Same trend was followed for the total weed dry weight also, with lower weed dry weights in methanol extraction (42.42 g/m^2) and cold water extraction (44.74 g/m^2), which were on par. Hot water extraction resulted in maximum weed dry weight (48.38 g/m^2).

Direct effect of concentration was not significant on grass weed dry weight; however, it was significant for broadleaved weeds and total weed dry weight. Lower dry weight (29.82 g/m^2) of broad leaved weeds was observed with 30 per cent concentration and 25 per cent (32.49 g/m^2), which were on par. Other concentrations were on par with each other. Maximum dry weight of broadleaved weeds was in control (49.02 g/m^2). The same trend was observed for the total weed dry weight also. The lowest dry weight (34.78 g/m^2) was recorded with 30 per cent concentration and was statistically on par with 25 per cent (37.48 g/m^2). Highest total weed dry weight (54.25 g/m^2) was recorded in control treatment.

Table 9. Direct effect of treatments on weed density and weed dry weight at one month after treatment application

Treatments	Weed density (no./m^2)			Weed dry weight (g/m^2)		
	Grasses	Broad leaved weeds	Total	Grasses	Broad leaved weeds	Total
Plants						
Andrographis paniculata	9.73 (94.60)	13.58 (186.21)	16.73 (280.81)	2.46 (5.05)	6.31 (39.50)	6.71 (44.55)
Plectranthus ambonicus	9.69 (93.82)	16.17 (260.36)	18.85 (354.18)	2.46 (5.06)	6.67 (44.56)	7.04 (49.62)
Tagetes minuta	9.70 (94.09)	13.26 (179.14)	16.48 (273.23)	2.44 (4.97)	6.10 (37.16)	6.45 (42.13)
CD (0.05)	NS	0.37	0.26	NS	0.20	0.19
Method of extraction						
Cold water extract	9.75 (94.44)	14.31 (208.14)	17.35 (302.58)	2.45 (5.01)	6.31 (39.73)	6.71 (44.74)
Hot water extract	9.72 (93.76)	14.77 (219.89)	17.69 (313.65)	2.46 (5.05)	6.63 (43.33)	7.00 (48.38)
Methanol extract	9.75 (93.71)	13.92 (198.17)	17.04 (291.88)	2.45 (5.02)	6.14 (37.40)	6.53 (42.42)
CD (0.05)	NS	0.37	0.26	NS	0.20	0.19
Concentration						
5%	9.73 (93.89)	14.80 (219.48)	17.70 (313.37)	2.46 (5.04)	6.70 (44.14)	7.07 (49.18)
10%	9.71 (93.67)	14.54 (213.04)	17.50 (306.71)	2.45 (5.01)	6.65 (43.37)	7.02 (48.38)
15%	9.74 (94.26)	14.28 (206.15)	17.31 (300.41)	2.45 (5.01)	6.52 (41.73)	6.89 (46.74)
20%	9.76 (94.48)	14.01 (198.78)	17.10 (293.26)	2.45 (5.00)	6.42 (40.49)	6.80 (45.49)
25%	9.71 (93.56)	13.42 (183.70)	16.60 (277.26)	2.45 (4.99)	5.71 (32.49)	6.14 (37.48)
30%	9.76 (94.37)	12.77 (168.33)	16.12 (262.70)	2.44 (4.96)	5.47 (29.82)	5.90 (34.78)
Control	9.76 (95.00)	16.51 (271.67)	19.17 (366.67)	2.49 (5.23)	7.05 (49.02)	7.42 (54.25)
CD (0.001)	NS	0.57	0.39	NS	0.31	0.29

** $\sqrt{x+0.5}$ transformed values, original values are given in parentheses

4.1.2. Two factor interactions

4.1.2.1. Interaction between plant and method of extraction

Germination count at weekly interval

Data on the interaction effect of allelopathic plant and method of extraction on weed germination count at weekly intervals up to one month are depicted in Table 10. Interaction was significant only during 1st week of observation. *Tagetes minuta* methanol extract showed significantly highest inhibitory influence (60 no./m^2) on germination count of weed seeds at 1st week. A total of 70.24 nos. of weeds/m^2 germinated in cold water extract of *Tagetes minuta* which was on par with methanol extract of *Andrographis paniculata* (69.76 no./m^2). Significantly minimum (161.42 no./m^2) allelopathic effect was exhibited by hot water extract of *Plectranthus ambonicus* which was on par with cold water extract of *Plectranthus ambonicus* (156.91 no./m^2).

Density of weeds at one month after application

Interaction effect of allelopathic plant and method of extraction had no significant influence on weed density of grasses, however, it was significant for density of broad leaved and total weeds at one month after application of treatments (Table 11).

Regarding broad leaved weeds, the lowest weed density at one month after application of treatments were observed in methanol extract of *Tagetes minuta* (165.90 no./m^2) followed by methanol extract of *Andrographis paniculata* (175.09 nos./m^2) and was on par with cold water extract of *Tagetes minuta* (176.52 no./m^2). Higher weed density was in *Plectranthus ambonicus* hot water extract (267.81 no./m^2) and was on par with cold water extract of *Plectranthus ambonicus* (261.24 no./m^2).

The total weed density at one month after application was lowest (260.47 no./m^2) with methanol extract of *Tagetes minuta* followed by methanol extract of *Andrographis paniculata* (269.33 no./m^2) and was on par with cold water extract of *Tagetes minuta* (270.19 no./m^2). Higher weed density was observed in *Plectranthus ambonicus* hot

water extract (360.57 no./m^2) which was on par with cold water extract of *Plectranthus ambonicus* (355.81 no./m^2).

Weed dry weight at one month after application

The data on the interaction effect of allelopathic plant with method of extraction on weed dry weight at one month after application are presented in the Table 12. Interaction was non significant for weed dry weight.

Table 10. Interaction effect of allelopathic plant and method of extraction on total weed count at weekly interval

Treatments	Weed count (No./m^2)											
	1st week			2nd week			3rd week			4th week		
	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract
A. paniculata	8.82 (81.90)	9.62 (95.24)	7.79 (69.76)	11.36 (129.05)	11.46 (131.43)	11.73 (137.62)	7.60 (58.09)	7.16 (51.19)	7.60 (57.62)	3.54 (12.71)	3.53 (12.52)	3.41 (11.71)
P. ambonicus	12.51 (156.91)	12.71 (161.42)	12.09 (146.43)	11.51 (132.38)	11.46 (131.43)	11.60 (134.52)	7.41 (55.24)	7.41 (55.24)	7.64 (58.33)	3.45 (12.24)	3.50 (12.48)	3.34 (11.48)
T. minuta	8.02 (70.24)	9.13 (86.90)	6.98 (60.00	11.41 (130.24)	11.46 (131.43)	11.42 (130.48)	7.04 (49.28)	7.42 (54.76)	7.56 (57.38)	3.46 (12.09)	3.43 (11.90)	3.46 (12.14)
CD (0.05)	0.37			NS			NS			NS		

** √x+0.5 transformed values, original values are given in parentheses

Table 11. Interaction effect of allelopathic plant and method of extraction on weed density one month after treatment application

Treatments	Weed density (No./m^2)								
	Grasses			Broad leaved			Total weeds		
	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract
A. paniculata	9.78 (95.09)	9.76 (94.48)	9.75 (94.24)	13.59 (186.67)	14.01 (196.86)	13.14 (175.09)	16.76 (281.76)	17.07 (291.34)	16.37 (269.33)
P. ambonicus	9.77 (94.57)	9.67 (92.76)	9.75 (94.14)	16.17 (261.24)	16.39 (267.81)	15.94 (253.52)	18.88 (355.81)	19.01 (360.57)	18.67 (347.66)
T. minuta	9.71 (93.67)	9.73 (94.05)	9.75 (94.57)	13.18 (176.52)	13.92 (195.00)	12.67 (165.90)	16.40 (270.19)	16.99 (289.05)	16.07 (260.47)
CD (0.05)	NS			0.52			0.29		

** √x+0.5 transformed values, original values are given in parentheses

Table 12. Interaction effect of allelopathic plant and method of extraction on weed dry weight one month after treatment application

Treatments	Weed dry weight (g/m^2)								
	Grasses			Broad leaved			Total weeds		
	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract
A. paniculata	2.46 (5.04)	2.46 (5.08)	2.46 (5.05)	6.23 (38.61)	6.64 (43.39)	6.07 (36.51)	6.63 (43.65)	7.01 (48.47)	6.48 (41.56)
P. ambonicus	2.46 (5.07)	2.46 (5.03)	2.47 (5.08)	6.67 (43.91)	6.75 (44.86)	6.59 (42.62)	7.05 (48.98)	7.11 (49.89)	6.97 (47.70)
T. minuta	2.44 (4.94)	2.46 (5.05)	2.43 (4.93)	6.04 (36.64)	6.50 (41.75)	5.76 (33.08)	6.45 (41.58)	6.88 (46.80)	6.16 (38.01)
CD (0.05)	NS			NS			NS		

** √x+0.5 transformed values, original values are given in parentheses

4.1.2.2. Interaction between allelopathic plant and concentration of extract

Germination count at weekly interval up to one month

Data on the interaction effect of allelopathic plant and concentration of extract on number of weeds germinated are presented in Table 13. This two factor interaction exhibited significant difference only during 1st week. The lowest weed germination count (27.78 no./m^2) was observed when *Tagetes minuta* was applied at higher concentration of 30 per cent followed by *Andrographis paniculata* at 30 per cent (31.67 no./m^2) and 25 per cent *Tagetes minuta* (37.78 no./m^2). The highest weed germination was observed in control (168.33 no./m^2) which was on par with all concentrations of *Plectranthus ambonicus*.

Density of weeds at one month after application

Data on interaction effect of treatments on weed density at one month after application are presented in Table 14. There was no significant difference in density of grass weeds. The lowest weed density (120.67 no./m^2) of broad leaved weeds was observed in *Tagetes minuta* at 30 per cent concentration. *Tagetes minuta* at 25 per cent concentration was the next best one with respect to lower weed density at one month after treatment application (130 no./m^2). The higher weed density (271.67 no./m^2) was recorded in control treatment and it was on par with all concentrations of *Plectranthus ambonicus*.

The same trend was observed for the total weed density. Weed density was minimum (215.34 no./m^2) in *Tagetes minuta* at 30 per cent concentration followed by 25 per cent concentration of *Tagetes minuta* (224.11no./m^2) and maximum (366.67 no./m^2) weed density was found in control treatment.

Weed dry weight at one month after application

Interaction between allelopathic plant and extract concentration on weed dry weight is depicted in the Table 15. Regarding dry weight of broad leaved weeds and total weeds, the lowest (23.34 and 27.89 g/m^2 respectively) was found in *Tagetes minuta* at higher concentration of 30 per cent followed by 25 per cent concentration (25.77 and 30.67 g/m^2 respectively). Control treatment had the higher dry weight of broad leaved (49.02 g/m^2) and total weeds (54.25 g/m^2).

Table 13. Interaction effect of allelopathic plant and concentration on total weed count at weekly intervals

Treatments	Weed count (No./m^2)											
	1st week			2nd week			3rd week			4th week		
	A. paniculata	*P. ambonicus*	*T. minuta*	*A. paniculata*	*P. ambonicus*	*T. minuta*	*A. paniculata*	*P. ambonicus*	*T. minuta*	*A. paniculata*	*P. ambonicus*	*T. minuta*
5%	9.61 (92.78)	12.78 (163.33)	9.06 (82.78)	11.53 (134.44)	11.51 (132.22)	11.82 (136.11)	7.34 (53.33)	7.39 (53.89)	7.50 (55.55)	3.62 (12.22)	3.58 (12.22)	3.46 (11.22)
10%	9.12 (83.33)	12.63 (159.44)	8.59 (75.00)	11.55 (137.22)	11.56 (132.78)	11.86 (136.11)	7.45 (55.55)	7.18 (51.11)	7.29 (52.78)	3.66 (12.44)	3.61 (12.33)	3.44 (10.89)
15%	8.45 (72.22)	12.41 (154.44)	7.80 (61.67)	11.60 (138.33)	11.57 (139.44)	12.01 (133.33)	7.53 (56.11)	7.35 (53.89)	7.22 (51.66)	3.48 (11.11)	3.43 (11.22)	3.68 (12.78)
20%	8.09 (66.11)	12.24 (150.00)	7.26 (53.33)	11.48 (138.33)	11.58 (137.78)	12.02 (133.89)	7.46 (55.00)	7.54 (56.67)	7.27 (52.22)	3.75 (13.11)	3.53 (11.67)	3.60 (12.22)
25%	7.81 (61.67)	12.10 (146.67)	6.07 (37.78)	11.39 (125.56)	11.38 (128.89)	11.02 (123.89)	7.57 (58.89)	7.88 (61.67)	7.42 (54.44)	3.53 (11.67)	3.39 (11.00)	3.49 (11.33)
30%	5.13 (31.67)	11.92 (142.22)	4.52 (27.78)	11.14 (123.33)	11.36 (126.67)	10.92 (120.00)	7.69 (53.33)	7.94 (63.33)	7.50 (56.67)	3.61 (12.33)	3.68 (12.67)	3.69 (12.56)
Control	12.98 (168.33)			11.51 (131.67)			7.30 (53.33)			3.65 (13.33)		
CD (0.05)	0.56			NS			NS			NS		

** √x+0.5 transformed values, original values are given in parentheses

Table 14. Interaction effect of allelopathic plant and concentration on weed density one month after treatment application

Treatments	Weed density (nos./m^2)								
	Grasses			Broad leaved			Total weeds		
	A. paniculata	*P. ambonicus*	*T. minuta*	*A. paniculata*	*P. ambonicus*	*T. minuta*	*A. paniculata*	*P. ambonicus*	*T. minuta*
5%	9.73 (94.00)	9.74 (94.11)	9.71 (93.56)	14.05 (196.56)	16.37 (267.00)	13.98 (194.89)	17.07 (290.56)	19.03 (361.11)	17.01 (288.45)
10%	9.77 (95.00)	9.74 (94.00)	9.63 (92.00)	13.77 (189.11)	16.19 (261.67)	13.66 (188.33)	16.88 (284.11)	18.88 (355.67)	16.74 (280.33)
15%	9.75 (94.33)	9.73 (93.78)	9.75 (94.67)	13.39 (179)	16.12 (259.11)	13.33 (180.33)	16.55 (273.33)	18.81 (352.89)	16.58 (275)
20%	9.83 (95.89)	9.68 (92.89)	9.76 (94.67)	13.02 (169.44)	16.10 (258.78)	12.93 (168.11)	16.31 (265.33)	18.77 (351.67)	16.21 (262.78)
25%	9.73 (94.00)	9.67 (92.56)	9.73 (94.11)	12.85 (165.44)	15.99 (255.67)	11.42 (130.00)	16.12 (259.44)	18.67 (348.22)	15.00 (224.11)
30%	9.74 (94.00)	9.76 (94.44)	9.77 (94.67)	11.46 (132.22)	15.89 (252.11)	10.95 (120.67)	15.04 (226.22)	18.63 (346.55)	14.68 (215.34)
Control	9.76 (95)			16.51 (271.67)			19.17 (366.67)		
CD (0.05)	NS			0.98			0.68		

** √x+0.5 transformed values, original values are given in parentheses

Table 15. Interaction effect of allelopathic plant and concentration on weed dry weight one month after treatment application

Treatments	Weed dry weight (g/m^2)								
	Grasses			Broad leaved			Total weeds		
	A. paniculata	*P. ambonicus*	*T. minuta*	*A. paniculata*	*P. ambonicus*	*T. minuta*	*A. paniculata*	*P. ambonicus*	*T. minuta*
5%	2.45 (4.99)	2.48 (5.15)	2.45 (4.98)	6.74 (44.67)	6.83 (45.96)	6.52 (41.79)	7.11 (49.66)	7.20 (51.11)	6.90 (46.77)
10%	2.46 (5.06)	2.44 (4.96)	2.44 (4.97)	6.64 (43.28)	6.81 (45.48)	6.49 (41.36)	7.02 (48.34)	7.17 (50.44)	6.87 (46.33)
15%	2.46 (5.03)	2.45 (5.00)	2.44 (4.95)	6.48 (41.08)	6.70 (44.06)	6.37 (40.05)	6.86 (46.11)	7.07 (49.07)	6.75 (45)
20%	2.46 (5.05)	2.46 (5.06)	2.43 (4.89)	6.37 (40.06)	6.60 (42.65)	6.30 (38.77)	6.76 (45.11)	6.97 (47.71)	6.67 (43.67)
25%	2.45 (5.02)	2.46 (5.04)	2.43 (4.90)	5.52 (29.98)	6.52 (41.73)	5.10 (25.77)	5.96 (35)	6.90 (46.77)	5.57 (30.67)
30%	2.45 (4.99)	2.45 (4.99)	2.43 (4.89)	5.37 (28.45)	6.19 (37.67)	4.85 (23.34)	5.82 (33.44)	6.58 (42.66)	5.31 (28.23)
Control	2.49 (5.23)			7.05 (49.02)			7.42 (54.25)		
CD (0.05)	NS			0.54			0.51		

** √x+0.5 transformed values, original values are given in parentheses

4.1.2.3. Interaction between method of extraction and concentration of extract

Germination count at weekly interval up to one month

Interaction effect of method of extraction and concentration of extract on weed germination count at weekly intervals is presented in the Table 16. Methanol extract at 30 per cent concentration recorded the lowest (50 no./m^2) germination count followed by cold water extract at 25 per cent concentration (65.56 no./m^2). Control treatment had the highest germination count of 168.33 no./m^2. During 2^{nd}, 3^{rd} and 4^{th} weeks of observation, interaction of treatments showed no significant influence on germination count of weeds.

Density of weeds at one month after application

Data on the weed density at one month after application as influenced by interaction between method of extraction and concentration of extract are furnished in Table 17. The data was non significant with respect to density of grasses, broad leaved weeds and also total weeds.

Weed dry weight at one month after application

Interaction effect of method of extraction and concentration of extract on weed dry weight at one month after application is presented in the Table 18. No significant interaction was observed for weed dry weight.

Table 16. Interaction effect of method of extraction and concentration on total weed count at weekly intervals

Treatments	Weed count (No./m^2)											
	1st week			2nd week			3rd week			4th week		
	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract
5%	10.60 (115.00)	11.05 (123.89)	9.81 (100.00)	11.50 (132.22)	11.47 (131.67)	11.78 (138.89)	7.50 (55.55)	7.26 (52.22)	7.46 (55.00)	3.43 (11.11)	3.67 (12.55)	3.57 (12.00)
10%	10.08 (105.56)	10.72 (117.22)	9.53 (95.00)	11.52 (132.78)	11.52 (132.78)	11.86 (140.56)	7.23 (52.22)	7.24 (51.66)	7.46 (55.55)	3.61 (12.11)	3.65 (12.56)	3.45 (11.00)
15%	9.43 (94.44)	10.42 (111.11)	8.81 (82.78)	11.57 (133.89)	11.55 (133.33)	12.02 (144.44)	7.10 (50.00)	7.30 (52.78)	7.71 (58.89)	3.54 (11.78)	3.48 (11.33)	3.57 (12.00)
20%	9.14 (88.89)	9.92 (102.22)	8.53 (78.33)	11.45 (131.11)	11.55 (133.33)	12.04 (145.00)	7.21 (51.67)	7.25 (52.22)	7.80 (60.00)	3.82 (13.67)	3.63 (12.22)	3.43 (11.11)
25%	8.78 (83.33)	9.34 (92.78)	7.86 (70.00)	11.35 (128.89)	11.35 (128.89)	10.98 (120.56)	7.53 (56.67)	7.45 (55.00)	7.89 (61.67)	3.44 (11.11)	3.63 (12.44)	3.34 (10.44)
30%	7.47 (65.56)	8.95 (86.11)	5.15 (50.00)	11.11 (123.33)	11.33 (128.33)	10.88 (118.33)	7.76 (60.00)	7.68 (58.89)	7.76 (60.00)	3.74 (13.33)	3.55 (11.67)	3.67 (12.56)
Control	12.98 (168.33)			11.47 (131.67)			7.30 (53.33)			3.65 (13.33)		
CD (0.05)	0.56			NS			NS			NS		

** √x+0.5 transformed values, original values are given in parentheses

Table 17. Interaction effect of method of extraction and concentration on weed density one month after treatment application

Treatments	Weed density (No./m^2)								
	Grasses			Broad leaved			Total weeds		
	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract
5%	9.76 (94.67)	9.68 (92.89)	9.74 (94.11)	14.87 (221.44)	15.10 (228)	14.43 (209)	17.78 (316.11)	17.92 (320.89)	17.40 (303.11)
10%	9.76 (94.67)	9.75 (94.44)	9.62 (91.89)	14.54 (212.44)	14.84 (220.89)	14.24 (205.78)	17.52 (307.11)	17.76 (315.33)	17.22 (297.67)
15%	9.74 (94.22)	9.70 (93.56)	9.78 (95)	14.14 (202.56)	14.89 (222.22)	13.81 (193.67)	17.20 (296.78)	17.78 (315.78)	16.96 (288.67)
20%	9.75 (94.56)	9.75 (94.33)	9.77 (94.56)	13.99 (198)	14.45 (210.11)	13.59 (188.22)	17.08 (292.56)	17.43 (304.44)	16.78 (282.78)
25%	9.69 (93.11)	9.61 (91.89)	9.82 (95.67)	13.40 (183.56)	13.94 (197.22)	12.92 (170.33)	16.57 (276.67)	16.96 (289.11)	16.25 (266)
30%	9.79 (94.89)	9.75 (94.22)	9.74 (94)	12.74 (167.33)	13.66 (189.11)	11.90 (148.56)	16.10 (262.22)	16.79 (283.33)	15.46 (242.56)
Control	9.76 (95)			16.51 (271.67)			19.17 (366.67)		
CD (0.05)	NS			NS			NS		

** √x+0.5 transformed values, original values are given in parentheses

Table 18. Interaction effect of method of extraction and concentration on weed dry weight one month after treatment application

Treatments	Weed dry weight (g/m^2)								
	Grasses			Broad leaved			Total weeds		
	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract
5%	2.45 (5.00)	2.47 (5.11)	2.45 (5.02)	6.71 (44.23)	6.86 (46.44)	6.53 (41.76)	7.07 (49.22)	7.23 (51.56)	6.90 (46.78)
10%	2.44 (4.97)	2.45 (5.02)	2.45 (5.01)	6.68 (43.81)	6.86 (46.09)	6.41 (40.21)	7.05 (48.78)	7.21 (51.11)	6.79 (45.22)
15%	2.45 (4.98)	2.46 (5.03)	2.44 (4.97)	6.57 (42.57)	6.67 (43.59)	6.32 (39.03)	6.94 (47.56)	7.04 (48.62)	6.70 (44)
20%	2.45 (5.01)	2.45 (5.02)	2.44 (4.97)	6.52 (41.88)	6.54 (41.91)	6.21 (37.70)	6.89 (46.89)	6.91 (46.93)	6.60 (42.67)
25%	2.44 (4.98)	2.45 (4.99)	2.45 (4.99)	5.53 (30.25)	6.32 (39.34)	5.30 (27.89)	5.97 (35.22)	6.70 (44.32)	5.76 (32.89)
30%	2.44 (4.95)	2.44 (4.97)	2.44 (4.95)	5.15 (26.33)	6.11 (36.93)	5.14 (26.22)	5.62 (31.33)	6.51 (41.89)	5.58 (30.78)
Control	2.49 (5.23)			7.05 (49.02)			7.42 (54.25)		
CD (0.05)	NS			NS			NS		

** √x+0.5 transformed values, original values are given in parentheses

4.1.3. Three factor interactions

4.1.3.1. Interaction between allelopathic plant, method of extraction and concentration

Germination count of weeds

Combined effect of allelopathic plant, method of extraction and concentration on germination count of weeds were recorded at weekly interval up to one month. The interaction was significant only during first week of observation and hence only significant data is provided in Table 19. Methanol extract of *Tagetes minuta* at 30 per cent concentration showed maximum (6.67 no./m^2) weed inhibition which was on par with methanol extract of *Andrographis paniculata* at 30 per cent (8.33 no./m^2) concentration. *Tagetes minuta*, 30 per cent cold water extract (23.33 no./m^2) was on par with 25 per cent methanol extract of *Tagetes minuta* (26.67 no./m^2). The control treatment recorded higher germination count (168.33 no./m^2) and was on par with all the treatment combinations with *Plectranthus ambonicus* except for methanol extract at 30 and 25 per cent concentrations.

Density of weeds at one month after application

Data pertaining to the influence of three factor interactions on density of weeds at one month after application are given in Table 20a, 20b and 20c. Treatment combination did not show any significant influence on density of grass weeds at one month of application. With respect to density of broad leaved weeds and total weeds interaction effect was significant. Lower broad leaf weed density was observed in 30 per cent methanol extract of *Tagetes minuta* (96.33 no./m^2) and was on par with 30 per cent methanol extract of *Andrographis paniculata* (107.67 no./m^2), 30 per cent cold water extract of *Tagetes minuta* (115.57 no./m^2), 25 per cent methanol and cold water extracts of *Tagetes minuta* (121.33 and 124.33 no./m^2, respectively). Higher broadleaf weed density was noticed in control treatment (271.67 no./m^2) and was on par with all treatment combinations with *Plectranthus ambonicus*.

Total weed density also followed same trend of broadleaf weed density with lower total weed density in 30 per cent methanol extract of *Tagetes minuta* (193.33 g/m^2) and was on par with 30 per cent cold water extract of *Tagetes minuta* (208.67 g/m^2), 30 per cent methanol extract of *Andrographis paniculata* (199.33 g/m^2), 25 per

cent methanol and cold water extracts of *Tagetes minuta* (216.67 and 218g/m^2, respectively). Higher broadleaf weed density was noticed in control treatment (366.67 g/m^2) and in all treatment combinations with *Plectranthus ambonicus*.

Weed dry weight at one month after application

Data on combined effect of three factors on weed dry weight at one month after application are presented in the Tables 21a, 21b and 21c. As in the case of density, interaction was non significant for dry weight of grasses at one month after application. Regarding broad leaved weed density, maximum suppression was observed in the treatment combinations of 25 and 30 per cent of cold water, methanol and hot water extracts of *Tagetes minuta* which was on par with combinations of 25 and 30 per cent of cold water and methanol extracts of *Andrographis paniculata.* Considering the total dry weight of weeds also, *Tagetes minuta* and *Andrographis paniculata* methanol and cold water extracts at 30 and 25 per cent concentrations exhibited maximum inhibitory effects.

Table 19. Interaction effect of allelopathic plant, method of extraction and concentration on germination count of weeds

Treatments	Weed count (No./m^2)								
	1st week								
	Andrographis paniculata			*Plectranthus ambonicus*			*Tagetes minuta*		
	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract
5%	9.66 (93.33)	10.33 (106.67)	8.85 (78.33)	12.91 (166.67)	12.98 (168.33)	12.45 (155.00)	9.21 (85.00)	9.83 (96.67)	8.15 (66.67)
10%	8.94 (80.00)	9.66 (93.33)	8.75 (76.67)	12.85 (165.00)	12.85 (165.00)	12.18 (148.33)	8.47 (71.67)	9.65 (93.33)	7.67 (60.00)
15%	8.16 (66.67)	9.66 (93.33)	7.52 (56.67)	12.60 (160.00)	12.65 (160.00)	11.97 (143.33)	7.52 (56.67)	8.94 (80.00)	6.94 (48.33)
20%	8.16 (66.67)	8.85 (78.33)	7.27 (53.33)	12.32 (151.67)	12.65 (160.00)	11.76 (138.33)	6.95 (48.33)	8.27 (68.33)	6.57 (43.33)
25%	8.06 (65.00)	8.56 (73.33)	6.80 (46.66)	12.10 (146.67)	12.52 (156.67)	11.69 (136.67)	6.19 (38.33)	7.27 (53.33)	5.09 (26.67)
30%	5.76 (33.33)	7.27 (53.33)	2.34 (8.33)	11.83 (140.00)	12.32 (151.67)	11.62 (135.00)	4.81 (23.33)	6.94 (48.33)	1.49 (6.67)
Control	12.98 (168.33)								
CD (0.05)	0.97								

** √x+0.5 transformed values, original values are given in parentheses

Table 20a. Interaction effect of allelopathic plant, method of extraction and concentration on grass weed density one month after treatment application

Treatments	Grass weed density (nos./m^2)								
	Andrographis paniculata			*Plectranthus ambonicus*			*Tagetes minuta*		
	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract
5%	9.79 (95.33)	9.67 (92.67)	9.73 (94.00)	9.80 (95.33)	9.67 (93.00)	9.74 (94.00)	9.71 (93.33)	9.68 (93.00)	9.75 (94.33)
10%	9.79 (95.67)	9.85 (96.33)	9.68 (93.00)	9.77 (94.67)	9.65 (92.33)	9.79 (95.00)	9.72 (93.67)	9.77 (94.67)	9.39 (87.67)
15%	9.79 (95.00)	9.75 (94.67)	9.71 (93.33)	9.74 (94.00)	9.65 (92.33)	9.80 (95.00)	9.70 (93.67)	9.69 (93.67)	9.84 (96.67)
20%	9.78 (95.00)	9.88 (96.67)	9.84 (96.00)	9.81 (95.33)	9.60 (91.67)	9.63 (91.67)	9.68 (93.33)	9.77 (94.67)	9.84 (96.00)
25%	9.71 (93.67)	9.62 (91.67)	9.87 (96.67)	9.64 (92.00)	9.56 (90.67)	9.80 (95.00)	9.72 (93.67)	9.66 (93.33)	9.80 (95.33)
30%	9.84 (96.00)	9.76 (94.33)	9.63 (91.67)	9.83 (95.67)	9.75 (94.33)	9.71 (93.33)	9.69 (93.00)	9.73 (94.00)	9.89 (97.00)
Control	9.76 (95)								
CD (0.05)	NS								

** √x+0.5 transformed values, original values are given in parentheses

Table 20b. Interaction effect of allelopathic plant, method of extraction and concentration on broad leaved weed density one month after treatment application

Treatments	Broad leaved weed density (nos./m^2)								
	Andrographis paniculata			*Plectranthus ambonicus*			*Tagetes minuta*		
	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract
5%	14.07 (197.33)	14.42 (207.00)	13.65 (185.33)	16.44 (269.67)	16.49 (271.00)	16.16 (260.33)	14.08 (197.33)	14.38 (206.00)	13.49 (181.33)
10%	13.70 (187.33)	13.81 (190.33)	13.80 (189.67)	16.29 (265.00)	16.42 (268.67)	15.88 (251.33)	13.64 (185.00)	14.30 (203.67)	13.06 (176.33)
15%	13.14 (172.33)	13.91 (193.00)	13.12 (171.67)	16.10 (259.00)	16.29 (264.33)	15.97 (254.00)	13.17 (176.33)	14.48 (209.33)	12.34 (155.33)
20%	13.16 (173.33)	13.42 (179.33)	12.47 (155.67)	15.97 (255.33)	16.49 (271.00)	15.84 (250.00)	12.86 (165.33)	13.45 (180.00)	12.48 (159.00)
25%	13.15 (174.33)	13.37 (178.00)	12.03 (144.00)	15.87 (252.00)	16.41 (269.33)	15.69 (245.67)	11.19 (124.33)	12.04 (144.33)	11.03 (121.33)
30%	11.38 (130.33)	12.62 (158.67)	10.38 (107.67)	16.03 (256.00)	16.10 (258.67)	15.55 (241.67)	10.80 (115.67)	12.26 (150.00)	9.79 (96.33)
Control	16.51 (271.67)								
CD (0.05)	1.40								

** √x+0.5 transformed values, original values are given in parentheses

Table 20c. Interaction effect of allelopathic plant, method of extraction and concentration on total weed density one month after treatment application

Treatments	Total weed density (nos./m^2)								
	Andrographis paniculata			*Plectranthus ambonicus*			*Tagetes minuta*		
	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract
5%	17.14 (292.66)	17.34 (299.67)	16.74 (279.33)	19.13 (365.00)	19.10 (364.00)	18.85 (354.33)	17.07 (290.67)	17.32 (299.00)	16.63 (275.67)
10%	16.85 (283.00)	16.96 (286.67)	16.83 (282.67)	18.98 (359.67)	19.03 (361.00)	18.64 (346.33)	16.72 (278.67)	17.29 (298.33)	16.20 (264.00)
15%	16.37 (267.33)	16.99 (287.67)	16.30 (265.00)	18.80 (353.00)	18.91 (356.67)	18.71 (349.00)	16.42 (270.00)	17.43 (303.00)	15.87 (252.00)
20%	16.40 (268.33)	16.63 (276.00)	15.88 (251.67)	18.74 (350.67)	19.06 (362.67)	18.51 (341.67)	16.11 (258.67)	16.60 (274.67)	15.94 (255.00)
25%	16.36 (268.00	16.45 (269.67)	15.54 (240.67)	18.55 (344.00)	18.98 (360.00)	18.47 (340.67)	14.80 (218.00)	15.45 (237.67)	14.74 (216.67)
30%	15.04 (226.33)	15.93 (253.00)	14.14b (199.33)	18.78 (351.67)	18.79 (353.00)	18.31 (335.00)	14.48 (208.67)	15.65 (244.00)	13.92 (193.33)
Control	19.17 (366.67)								
CD (0.05)	1.10								

** √x+0.5 transformed values, original values are given in parentheses

Table 21a. Interaction effect of allelopathic plant, method of extraction and concentration on dry weight of grasses one month after treatment application

Treatments	Dry weight of grasses (g/m^2)								
	Andrographis paniculata			*Plectranthus ambonicus*			*Tagetes minuta*		
	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract
5%	2.44 (4.94)	2.46 (5.03)	2.45 (5.01)	2.48 (5.14)	2.49 (5.18)	2.48 (5.13)	2.43 (4.91)	2.47 (5.13)	2.43 (4.91)
10%	2.46 (5.04)	2.45 (5.02)	2.47 (5.12)	2.44 (4.95)	2.43 (4.93)	2.45 (5.01)	2.43 (4.91)	2.47 (5.11)	2.43 (4.90)
15%	2.47 (5.09)	2.45 (5.00)	2.45 (5.01)	2.44 (4.95)	2.45 (5.01)	2.46 (5.05)	2.43 (4.90)	2.46 (5.08)	2.42 (4.86)
20%	2.45 (5.01)	2.48 (5.15)	2.45 (5.00)	2.48 (5.14)	2.44 (4.97)	2.46 (5.05)	2.42 (4.87)	2.44 (4.95)	2.42 (4.86)
25%	2.44 (4.97)	2.46 (5.07)	2.45 (5.03)	2.46 (5.07)	2.44 (4.96)	2.47 (5.08)	2.42 (4.88)	2.44 (4.93)	2.42 (4.88)
30%	2.45 (5.01)	2.45 (5.03)	2.44 (4.94)	2.45 (4.99)	2.44 (4.96)	2.45 (5.03)	2.42 (4.86)	2.43 (4.92)	2.42 (4.88)
Control	2.49 (5.23)								
CD (0.05)	NS								

** √x+0.5 transformed values, original values are given in parentheses

Table 21b. Interaction effect of allelopathic plant, method of extraction and concentration on dry weight of broad leaved weeds one month after treatment application

Treatments	Dry weight of broad leaved weeds (g/m^2)								
	Andrographis paniculata			*Plectranthus ambonicus*			*Tagetes minuta*		
	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract
5%	6.71 (44.06)	6.85 (46.30)	6.68 (43.66)	6.75 (45.20)	7.00 (48.16)	6.74 (44.53)	6.66 (43.42)	6.74 (44.87)	6.71 (37.09)
10%	6.64 (43.30)	6.82 (45.65)	6.46 (40.88)	6.78 (45.05)	7.00 (48.07)	6.65 (43.33)	6.62 (43.09)	6.74 (44.56)	6.64 (36.43)
15%	6.55 (41.91)	6.63 (43)	6.26 (38.33)	6.74 (44.71)	6.78 (45.19)	6.58 (42.29)	6.41 (41.10)	6.60 (42.59)	6.55 (36.48)
20%	6.40 (40.99)	6.59 (42.52)	6.40 (40.27)	6.72 (44.19)	6.66 (43.48)	6.41 (40.28)	6.43 (40.46)	6.37 (39.72)	6.40 (36.14)
25%	5.23 (26.36)	6.31 (39.26)	5.02 (24.30)	6.62 (42.93)	6.50 (41.68)	6.43 (40.59)	4.74 (21.45)	6.13 (37.07)	5.23 (18.79)
30%	5.05 (24.66)	6.19 (37.97)	4.86 (22.73)	6.04 (36.32)	6.25 (38.39)	6.26 (38.30)	4.35 (18.00)	5.89 (34.41)	5.05 (17.62)
Control	7.05 (49.02)								
CD (0.05)	1.28								

** √x+0.5 transformed values, original values are given in parentheses

Table21c. Interaction effect of allelopathic plant, method of extraction and concentration on dry weight of total weeds one month after treatment application

Treatments	Dry weight of total weeds (g/m^2)								
	Andrographis paniculata			*Plectranthus ambonicus*			*Tagetes minuta*		
	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract	Cold water extract	Hot water extract	Methanol extract
5%	7.07 (49.00)	7.21 (51.33)	7.04 (48.67)	7.13 (50.33)	7.36 (53.33)	7.11 (49.67)	7.02 (48.33)	7.12 (50.00)	6.55 (42.00)
10%	7.01 (48.33)	7.18 (50.67)	6.85 (46.00)	7.14 (50.00)	7.34 (53.00)	7.02 (48.33)	6.99 (48.00)	7.11 (49.67)	6.50 (41.33)
15%	6.92 (47.00)	7.00 (48.00)	6.65 (43.33)	7.10 (49.67)	7.14 (50.20)	6.95 (47.33)	6.79 (46.00)	6.97 (47.67)	6.50 (41.33)
20%	6.79 (46.00)	6.97 (47.67)	6.52 (41.67)	7.09 (49.33)	7.02 (48.45)	6.80 (45.33)	6.79 (45.33)	6.75 (44.67)	6.48 (41.00)
25%	5.68 (31.33)	6.71 (44.33)	5.50 (29.33)	6.99 (48.00)	6.88 (46.64)	6.81 (45.67)	5.23 (26.33)	6.52 (42.00)	4.96 (23.67)
30%	5.53 (29.67)	6.59 (43.00)	5.35 (27.67)	6.45 (41.32)	6.64 (43.35)	6.65 (43.33)	4.89 (23.00)	6.30 (39.33)	4.72 (21.33)
Control	7.42 (54.25)								
CD (0.05)	1.70								

** √x+0.5 transformed values, original values are given in parentheses

4.2. Experiment 2 A. Allelopathic effect of plant extracts on weeds and test crops

4.2.1. Direct effect of treatments

4.2.1.1. Observations on test crops

Days to first germination

Germination count of three test crops *viz*., cowpea, green gram and rice were observed daily for 15 days and data are presented in Tables 22a, 22b and 22c.

For cowpea, the first germination was observed on the 2nd day of sowing in the control treatment. Delay in germination as compared to control was observed by the application of various extracts of *Tagetes minuta* and *Andrographis paniculata*. Maximum delay in germination was observed in 30 and 25 per cent methanol and cold water extracts of *Tagetes minuta* and *Andrographis paniculata*. In these treatments germination started only on 4th day of sowing and only single seed germinated on 4th day. It took 12 days to complete germination in treatments with 30 and 25 per cent methanol extract and 30 per cent cold water extract of *Tagetes minuta* whereas only three days were taken for complete germination in control treatment.

Regarding green gram, maximum delay in germination was observed in the treatment 30 per cent methanol extract of *Tagetes minuta*, which took 5 days to start germination as compared to single day in control treatment. It took 11 days to complete germination in this treatment as compared to three days in control treatment.

Germination of rice seeds started on 6th day after sowing and completed on 9th day in control treatment. The seeds treated with extracts of allelopathic plants showed extended germination time. It took 14 days to complete germination in methanol extract of *Andrographis paniculata* at 30 per cent, cold water extract of *Tagetes minuta* at 30 per cent, methanol extract of *Tagetes minuta* at 25 and 30 per cent.

Table 22a. Germination count of cowpea daily up to 15 days

COWPEA (Days)												
Treatment	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Cold water extract of *A. paniculata* @ 25 %	0	0	1	3	2	3	2	1				
Cold water extract of *A. paniculata* @ 30 %	0	0	1	2	2	2	1	2	1	1		
Methanol extract of *A. paniculata* @ 25 %	0	0	0	1	4	2	1	2	2			
Methanol extract of *A. paniculata* @ 30 %	0	0	0	1	1	2	3	1	2	1	1	
Cold water extract of *T. minuta* @ 25 %	0	0	0	1	0	3	1	2	2	2	1	
Cold water extract of *T. minuta* @ 30 %	0	0	0	1	0	2	3	1	1	1	2	1
Hot water extract of *T. minuta* @ 25 %	0	0	1	3	3	2	1	2				
Hot water extract of *T. minuta* @ 30 %	0	0	1	3	1	1	1	1	2	1	1	
Methanol extract of *T. minuta* @ 25 %	0	0	0	0	1	2	2	1	2	2	1	1
Methanol extract of *T. minuta* @ 30 %	0	0	0	0	1	2	1	1	2	3	1	1
Control (distilled water)		9	3									

Table 22b. Germination count of green gram daily up to 15 days

GREEN GRAM (Days)											
Treatment	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Cold water extract of *A. paniculata* @ 25 %	0	0	1	3	2	2	3	1	1		
Cold water extract of *A. paniculata* @ 30 %	0	0	1	3	2	2	2	2			
Methanol extract of *A. paniculata* @ 25 %	0	0	1	2	2	3	2	1	1		
Methanol extract of *A. paniculata* @ 30 %	0	0	1	1	4	1	3	1	1		
Cold water extract of *T. minuta* @ 25 %	0	0	1	2	2	1	2	3	1		
Cold water extract of *T. minuta* @ 30 %	0	0	0	0	3	2	4	2	1		
Hot water extract of *T. minuta* @ 25 %	0	0	1	6	2	1	2				
Hot water extract of *T. minuta* @ 30 %	0	0	1	2	4	2	2	1			
Methanol extract of *T. minuta* @ 25 %	0	0	0	1	2	2	3	2	2		
Methanol extract of *T. minuta* @ 30 %	0	0	0	0	1	2	2	1	4	1	1
Control (distilled water)	1	9	2								

Table 22c. Germination count of rice daily up to 15 days

RICE (Days)									
Treatment	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Cold water extract of *A. paniculata* @ 25 %	1	3	2	1	3	1	1		
Cold water extract of *A. paniculata* @ 30 %	1	2	3	2	1	1	1	1	
Methanol extract of *A. paniculata* @ 25 %	1	2	0	3	2	3	1		
Methanol extract of *A. paniculata* @ 30 %	1	2	0	3	2	1	1	1	1
Cold water extract of *T. minuta* @ 25 %	0	2	1	1	1	2	2	2	
Cold water extract of *T. minuta* @ 30 %	0	2	2	1	2	1	2	1	2
Hot water extract of *T. minuta* @ 25 %	2	1	3	2	2	1	1		
Hot water extract of *T. minuta* @ 30 %	1	1	1	1	2	1	2	2	
Methanol extract of *T. minuta* @ 25 %	0	1	2	1	2	1	2	2	2
Methanol extract of *T. minuta* @ 30 %	0	1	1	1	2	1	3	2	2
Control (distilled water)	6	4	1	1					

Speed of germination

The data on speed of germination of cowpea, green gram and rice are presented in Table 23. Treatments significantly influenced speed of germination of selected dicots and monocot plant. All the treatments recorded lower speed of germination as compared to control. Germination speed ranged from 1.55 no./day to 5.5 no./day for cowpea, 1.63 no./day to 6.17 no./day for green gram and 1.06 no./day to 1.81 no./day for rice.

In cowpea, the lower speed of germination was noticed in 30 per cent *Tagetes minuta* methanol extract (1.55 no./day) and was on par with 25 per cent *Tagetes minuta* methanol extract (1.58 no./day), 30 and 25 per cent *Tagetes minuta* cold water extracts (1.62 and 1.66 no./day, respectively). Maximum speed of germination was observed in control treatment (5.5 no./day).

Regarding green gram, lowest speed of germination was in 30 per cent *Tagetes minuta* methanol extract (1.63 no./day) followed by 25 per cent *Tagetes minuta* methanol extract (1.89 no./day). Control treatment recorded a speed of germination of 6.17 no./day.

Rice seeds treated with 30 percent *Tagetes minuta* methanol extract recorded the lowest germination speed (1.06 no./day) followed by 25 per cent methanol extract of *Tagetes minuta* (1.12 no./day). Germination speed of rice was faster in control treatment (1.81 no./day).

Table 23. Effects of allelopathic extracts on speed of germination of cowpea, green gram and rice

Allelopathic extracts	Speed of germination (No./day)		
	Cowpea	Green gram	Rice
Cold water extract of *A. paniculata* @ 25 %	2.39	2.48	1.43
Cold water extract of *A. paniculata* @ 30 %	2.17	2.35	1.41
Methanol extract of *A. paniculata* @ 25 %	2.01	2.25	1.31
Methanol extract of *A. paniculata* @ 30 %	1.75	2.21	1.24
Cold water extract of *T. minuta* @ 25 %	1.66	2.16	1.12
Cold water extract of *T. minuta* @ 30 %	1.62	2.01	1.21
Hot water extract of *T. minuta* @ 25 %	2.41	2.69	1.45
Hot water extract of *T. minuta* @ 30 %	2.12	2.37	1.24
Methanol extract of *T. minuta* @ 25 %	1.58	1.89	1.12
Methanol extract of *T. minuta* @ 30 %	1.55	1.63	1.06
Control (distilled water)	5.5	6.17	1.81
CD (0.05)	0.06	0.08	0.05

Shoot length of cowpea, green gram and rice at 7 and 15 DAS

Shoot length at 7 DAS

Table 24a depicts the direct effect of time of application and allelopathic extracts on the shoot length of cowpea, green gram and rice in petri plates. Individual direct effect of each factor was statistically significant on shoot length of cowpea, green gram and rice at 7 days after sowing.

Regarding time of application, allelopathic treatments were effective when applied on the day of sowing. Shoot lengths were 5.1 cm, 5.60 cm and 1.12 cm respectively for cowpea, green gram and rice when sprayed with allelopathic extracts on the day of sowing. When treatments were applied on 6th day after sowing, the shoot lengths of cowpea, green gram and rice were 7.7 cm, 7.44 cm and 1.41 cm respectively.

Perusal of data on direct effect of allelopathic extracts on shoot length of cowpea, green gram and rice revealed the inhibitory effect of extracts on shoot length. As compared to control treatment, significant reduction in shoot length of all crops studied were observed. In cowpea maximum reduction in shoot length was observed in treatment with 30 per cent methanol extract of *Tagetes minuta* (6.39 cm as compared to 7.5 cm in control).

In the case of green gram, maximum shoot length reduction was observed in *Tagetes minuta* methanol extract at 30 and 25 per cent concentration and with the treatment of 30 per cent cold water extract of *Tagetes minuta* (6.08 cm). Highest shoot length was observed in control treatment (7.47 cm).

Rice shoot length reduction was higher in the treatment with *Tagetes minuta* 30 per cent methanol extract and was on par with other treatments with allelopathic extracts. Maximum shoot length was observed in control treatment (1.47 cm).

Shoot length at 15 DAS

The data on the direct effect of time of application and allelopathic extracts on shoot length of cowpea, green gram and rice observed at 15 days after sowing are presented Table 24b.

More pronounced shoot length suppression was noticed when treatments were applied on the day of sowing as compared to 6th day of sowing. The significantly lower shoot length of 11.41 cm in cowpea, 11.04 cm in green gram and 4.45 cm in rice were recorded when treatments were applied on the day of sowing. The highest shoot length was observed when treatments were applied on 6th day of sowing (11.85 cm, 10.80 cm and 4.86 cm in cowpea, green gram and rice, respectively).

Cowpea recorded maximum shoot length reduction when treated with 30 per cent methanol and cold water extracts of *Tagetes minuta* (11.33 and 11.34 cm, respectively). These treatments were on par and followed by 25 per cent cold water extract of *Tagetes minuta* (11.43 cm). Control treatment recorded higher shoot length (11.86 cm) and was on par with 25 and 30 per cent cold water extract of *Andrographis paniculata* (11.81 and 11.78 cm, respectively).

In case of green gram, shoot growth inhibition was more pronounced in 25 and 30 per cent concentration of methanol extract of *Tagetes minuta* (10.57 cm and 10.58 cm respectively) followed by cold water extract of *Tagetes minuta* at 30 per cent concentration. Maximum shoot growth was recorded with hot water extract of *Tagetes minuta* and cold water extract of *Andrographis paniculata* at 25 per cent concentration (11.28 cm and 11.26 cm respectively).

The lowest shoot length of rice was in 30 per cent *Tagetes minuta* methanol extract (4.32 cm) followed by 25 per cent *Tagetes minuta* methanol extract (4.44 cm). Maximum shoot length was recorded from the control treatment (4.90 cm) and was on par with *Tagetes minuta* hot water extract and *Andrographis paniculata* cold water extracts at 25 per cent concentration (4.89 and 4.87 cm, respectively).

Table 24a. Shoot length of cowpea, green gram and rice at 7 days after sowing

	Cowpea	Green gram	Rice
Time of application			
On the day of sowing	5.81	5.60	1.12
6th day of sowing	7.87	7.44	1.41
CD (0.05)	0.17		
Allelopathic extracts			
Cold water extract of *A. paniculata* @ 25 %	7.15	6.84	1.39
Cold water extract of *A. paniculata* @ 30 %	6.83	6.70	1.34
Methanol extract of *A. paniculata* @ 25 %	6.79	6.42	1.27
Methanol extract of *A. paniculata* @ 30 %	6.59	6.36	1.21
Cold water extract of *T. minuta* @ 25 %	6.56	6.34	1.26
Cold water extract of *T. minuta* @ 30 %	6.47	6.08	1.16
Hot water extract of *T. minuta* @ 25 %	7.40	6.97	1.29
Hot water extract of *T. minuta* @ 30 %	6.68	6.40	1.24
Methanol extract of *T. minuta* @ 25 %	6.51	6.08	1.19
Methanol extract of *T. minuta* @ 30 %	6.39	6.08	1.11
Control (distilled water)	7.85	7.47	1.47
CD (0.05)	0.07		

Table 24b. Shoot length of cowpea, green gram and rice at 15 days after sowing

	Cowpea	Green gram	Rice
Time of application			
On the day of sowing	11.41	10.80	4.73
6th day of sowing	11.85	11.04	4.86
CD (0.05)	0.17		
Allelopathic extracts			
Cold water extract of *A. paniculata* @ 25 %	11.81	11.26	4.87
Cold water extract of *A. paniculata* @ 30 %	11.78	11.17	4.77
Methanol extract of *A. paniculata* @ 25 %	11.70	11.17	4.66
Methanol extract of *A. paniculata* @ 30 %	11.55	10.80	4.56
Cold water extract of *T. minuta* @ 25 %	11.43	10.81	4.61
Cold water extract of *T. minuta* @ 30 %	11.34	10.67	4.56
Hot water extract of *T. minuta* @ 25 %	11.55	11.28	4.89
Hot water extract of *T. minuta* @ 30 %	11.66	11.01	4.66
Methanol extract of *T. minuta* @ 25 %	11.88	10.57	4.44
Methanol extract of *T. minuta* @ 30 %	11.33	10.58	4.32
Control (distilled water)	11.86	10.81	4.90
CD (0.05)	0.07		

Root length of cowpea, green gram and rice at 7 and 15 DAS

Root length at 7 DAS

Data on direct effect of time of application and allelopathic extracts on root length of three test crops are present in the Table 25a. Direct effect of time of application and allelopathic extracts were statistically significant for cowpea, green gram and rice. However, direct effect of allelopathic extracts were significant only for cowpea and green gram.

As in the case of shoot length, effect of treatments was more pronounced when applied on the day of sowing. Root lengths were 2.50 cm, 2.39 cm and 1.11 cm, respectively for cowpea, green gram and rice when treatments were applied on the day of sowing. Root lengths of 3.34 cm, 3.27 cm and 1.24 cm, respectively for cowpea, green gram and rice were observed when treatments were applied at 6th day of sowing.

Among allelopathic extracts, maximum root suppression was recorded when cowpea seeds were treated with 30 and 25 per cent methanol extracts of *Tagetes minuta* (2.67 cm and 2.69 cm respectively) followed by 25 and 30 per cent cold water extracts of *Tagetes minuta* and 25 per cent *Andrographis paniculata* methanol extract.

Root growth reduction in green gram was higher in treatments 30 and 25 per cent *Tagetes minuta* methanol extract (2.58 and 2.59 cm, respectively) and in cold water extract of *Tagetes minuta* at 30 per cent concentration (2.62 cm). Highest root length of 3.28 cm was observed in control treatment.

Root length at 15 DAS

Table 25b depicts the direct influence of factors on root length of crops at 15 days after treatment application. Maximum allelopathic influence was noticed when extracts were applied on the day of sowing, which resulted in root lengths of 5.40 cm, 5.17 cm and 6.47 cm, respectively in cowpea, green gram and rice. Root length of cowpea, green gram and rice when treated with extracts on 6th day of sowing was 5.76 cm, 5.45 cm and 6.64 cm, respectively.

The lowest cowpea root length was observed in 30 per cent methanol extract of *Tagetes minuta* (5.24 cm) followed by its 25 per cent concentration (5.32 cm). Higher root length of 5.79 cm was recorded from the treatment with control.

Root growth inhibition of green gram was more pronounced in 30 and 25 per cent *Tagetes minuta* methanol extracts (5.08 and 5.14 cm, respectively) and was on par with cold water extract of *Tagetes minuta* at 30 per cent concentration (5.15 cm). Higher root length of 5.50 cm was recorded from cold water extract of *Andrographis paniculata* at 25 per cent concentration.

The lowest length of rice roots were recorded from treatments with 30 and 25 per cent methanol extract of *Tagetes minuta* (6.20 and 6.22 cm, respectively) and was on par with 30 per cent *Tagetes minuta* cold water extract (6.23 cm). The highest root length of 6.63 cm was observed from control treatment and was on par with hot water extract of *Tagetes minuta* at 25 per cent concentration (6.57 cm).

Table 25a. Root length of cowpea, green gram and rice at 7 days after sowing

	Cowpea	Green gram	Rice
Time of application			
On the day of sowing	2.50	2.39	1.11
6th day of sowing	3.34	3.27	1.24
CD (0.05)	0.17		
Allelopathic extracts			
Cold water extract of *A. paniculata* @ 25 %	3.15	2.93	1.23
Cold water extract of *A. paniculata* @ 30 %	3.00	2.87	1.21
Methanol extract of *A. paniculata* @ 25 %	2.85	2.86	1.22
Methanol extract of *A. paniculata* @ 30 %	2.79	2.75	1.21
Cold water extract of *T. minuta* @ 25 %	2.79	2.77	1.17
Cold water extract of *T. minuta* @ 30 %	2.79	2.62	1.11
Hot water extract of *T. minuta* @ 25 %	3.14	3.08	1.25
Hot water extract of *T. minuta* @ 30 %	2.94	2.81	1.23
Methanol extract of *T. minuta* @ 25 %	2.69	2.59	1.07
Methanol extract of *T. minuta* @ 30 %	2.67	2.58	0.99
Control (distilled water)	3.32	3.28	1.23
CD (0.05)	0.07		NS

Table 25b. Root length of cowpea, green gram and rice at 15 days after sowing

	Cowpea	Green gram	Rice
Time of application			
On the day of sowing	5.40	5.17	6.47
6th day of sowing	5.76	5.45	6.64
CD (0.05)		0.17	
Allelopathic extracts			
Cold water extract of *A. paniculata* @ 25 %	5.73	5.50	6.47
Cold water extract of *A. paniculata* @ 30 %	5.73	5.42	6.48
Methanol extract of *A. paniculata* @ 25 %	5.68	5.39	6.42
Methanol extract of *A. paniculata* @ 30 %	5.62	5.25	6.32
Cold water extract of *T. minuta* @ 25 %	5.60	5.27	6.31
Cold water extract of *T. minuta* @ 30 %	5.41	5.15	6.23
Hot water extract of *T. minuta* @ 25 %	5.68	5.42	6.57
Hot water extract of *T. minuta* @ 30 %	5.62	5.31	6.34
Methanol extract of *T. minuta* @ 25 %	5.32	5.14	6.22
Methanol extract of *T. minuta* @ 30 %	5.24	5.08	6.20
Control (distilled water)	5.79	5.42	6.63
CD (0.05)		0.07	

Fresh weight of cowpea, green gram and rice at 7 and 15 DAS

Fresh weight at 7 DAS

Data on direct influence of allelopathic effect of treatments and time of application on fresh weight of field crops are depicted in the Table 26a. There was significant influence of time of application on fresh weight of cowpea and green gram at 7 days after sowing, but not for rice. Also fresh weight of test crops was not influenced by allelopathic extracts at 7 DAS.

Maximum reduction of fresh weight of test crops were observed when treatment were applied on the same day of sowing observed which were 0.04, 0.04 and 0.01 g/plant, respectively for cowpea, green gram and rice. The fresh weights of test crops were 0.10, 0.10 and 0.06 g/plant, respectively when sprayed at 6 days after sowing.

Fresh weight at 15DAS

Table 26b depicts the data on fresh weight of test crops at 15 days after sowing. Time of application was significant only for cowpea and green gram. Maximum fresh weight reduction was recorded when treatment applied at on the day of sowing for cowpea and green gram (0.48 and 0.41 g/plant, respectively) followed by the treatment sprayed at 6^{th} day of sowing (0.49 and 0.42 g/plant, respectively).

Table 26a. Fresh weight of cowpea, green gram and rice at 7 days after sowing

	Cowpea	Green gram	Rice
Time of application			
On the day of sowing	0.04	0.04	0.01
6th day of sowing	0.10	0.10	0.06
CD (0.05)	0.08		NS
Allelopathic extracts			
Cold water extract of *A. paniculata* @ 25 %	0.05	0.05	0.01
Cold water extract of *A. paniculata* @ 30 %	0.05	0.05	0.01
Methanol extract of *A. paniculata* @ 25 %	0.05	0.05	0.01
Methanol extract of *A. paniculata* @ 30 %	0.05	0.05	0.01
Cold water extract of *T. minuta* @ 25 %	0.05	0.05	0.01
Cold water extract of *T. minuta* @ 30 %	0.19	0.19	0.17
Hot water extract of *T. minuta* @ 25 %	0.05	0.04	0.01
Hot water extract of *T. minuta* @ 30 %	0.05	0.05	0.01
Methanol extract of *T. minuta* @ 25 %	0.05	0.04	0.01
Methanol extract of *T. minuta* @ 30 %	0.15	0.15	0.13
Control (distilled water)	0.06	0.06	0.02
CD (0.05)	NS		

Table 26b. Fresh weight of cowpea, green gram and rice at 15 days after sowing

	Cowpea	Green gram	Rice
Time of application			
On the day of sowing	0.48	0.41	0.28
6th day of sowing	0.49	0.42	0.29
CD (0.05)	0.01		NS
Allelopathic extracts			
Cold water extract of *A. paniculata* @ 25 %	0.52	0.42	0.28
Cold water extract of *A. paniculata* @ 30 %	0.50	0.41	0.27
Methanol extract of *A. paniculata* @ 25 %	0.49	0.40	0.27
Methanol extract of *A. paniculata* @ 30 %	0.48	0.38	0.26
Cold water extract of *T. minuta* @ 25 %	0.49	0.40	0.27
Cold water extract of *T. minuta* @ 30 %	0.49	0.46	0.41
Hot water extract of *T. minuta* @ 25 %	0.48	0.43	0.27
Hot water extract of *T. minuta* @ 30 %	0.49	0.41	0.27
Methanol extract of *T. minuta* @ 25 %	0.45	0.39	0.26
Methanol extract of *T. minuta* @ 30 %	0.46	0.37	0.26
Control (distilled water)	0.48	0.41	0.27
CD (0.05)	NS		

4.2.3. Two factor interactions

4.2.3.1. Interaction between time of application and allelopathic extracts

a. Interaction between time of application and allelopathic extracts on shoot length of cowpea, green gram and rice

Shoot length of cowpea at 7 DAS and 15 DAS

The data on interaction effect of time of application and allelopathic extracts on shoot length of cowpea at 7 and 15 days after sowing are presented in the Table 27a. Allelopathic influence of treatments on cowpea shoot length was significance both at 7 and 15 days after sowing.

Shoot length at 7 DAS

Higher reduction in shoot length of cowpea was observed in the *Tagetes minuta* 30 per cent methanol extract (4.92 cm) and in 25 per cent *Tagetes minuta* methanol extracts (4.99 cm). These treatments were on par with 30 and 25 per cent cold water extracts of *Tagetes minuta* (5.16 and 5.25 cm, respectively) and 30 per cent methanol extract of *Andrographis paniculata* (5.27 cm) applied on the day of sowing. Control treatment recorded the highest shoot length of 7.85 cm. Shoot length in treatments which received application of extracts at 6 days after sowing *i.e*. one day before taking observation did not show significant difference with respect to shoot length at 7 DAS.

Shoot length at 15 DAS

Allelopathic potential of *Tagetes minuta* extracts were evident on shoot length of cowpea. The lower shoot length of 10.77 cm was observed in 30 per cent methanol extract of *Tagetes minuta* and was on par with 30 and 25 per cent cold water extracts of *Tagetes minuta* (10.88 and 11.01 cm, respectively) which were applied on the day of sowing. As in the case of shoot length, also not showed significant difference when extracts were applied on 6^{th} day after sowing.

Shoot length of green gram at 7 DAS and 15 DAS

Shoot length of green gram at 7 and 15 days after sowing are presented in the Table 27b.

Shoot length at 7 DAS

Tagetes minuta methanol extract at 30 per cent concentration sprayed at the time of sowing recorded lower shoot length of 4.65 cm and was on par with 25 per cent methanol extract of *Tagetes minuta* sprayed at the time of sowing (4.72 cm) and 30 per cent cold water extract of *Tagetes minuta* (4.76 cm). Control treatment recorded a shoot length of 7.47 cm. Shoot length in treatments which received application of extracts at 6 days after sowing *i.e*. one day before taking observation did not show significant difference with respect to shoot length at 7 DAS.

Shoot length at 15 DAS

Maximum shoot length reduction in green gram was recorded from 30 and 25 per cent methanol extract of *Tagetes minuta* (10.31 and 10.39 cm, respectively) sprayed on the same day of sowing. The control treatment recorded shoot length of 11.81 cm.

Shoot length of rice at 7 DAS and 15 DAS

The data on interaction between time of application and allelopathic extracts on shoot length of rice observed at 7 and 15 days after sowing is presented in Table 27c.

Shoot length at 7 DAS

Maximum suppression of shoot length of rice (0.86 and 0.92 cm, respectively) was observed when treated with 30 and 25 per cent *Tagetes minuta* methanol extract and was on par with other treatments applied on the same day of sowing except with 25 per cent cold water extract of *Andrographis paniculata* and hot water extract of *Tagetes minuta*. Shoot length of control treatment was 1.47 cm. Shoot length in treatments which received application of extracts at 6 days after sowing *i.e*. one day before taking observation did not show significant difference with respect to shoot length at 7 DAS.

Shoot length at 15 DAS

Higher shoot length inhibition of rice was observed in the treatments applied on the same day of sowing (3.89 cm) and was on par with all other treatments applied on the same day of sowing except 25 per cent cold water extract of *Andrographis paniculata* and hot water extract of *Tagetes minuta*. Control treatment recorded shoot length of 4.90 cm.

Table 27a. Interaction between time of application and allelopathic extracts on shoot length (cm) of cowpea

Allelopathic extracts	Time of application			
	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing
	Observation at 7th day of sowing		Observation at 15th day of sowing	
Cold water extract of *A. paniculata* @ 25 %	6.55	7.76	11.81	11.81
Cold water extract of *A. paniculata* @ 30 %	5.86	7.80	11.63	11.93
Methanol extract of *A. paniculata* @ 25 %	5.74	7.87	11.60	11.83
Methanol extract of *A. paniculata* @ 30 %	5.27	7.90	11.26	11.84
Cold water extract of *T. minuta* @ 25 %	5.25	7.87	11.01	11.85
Cold water extract of *T. minuta* @ 30 %	5.16	7.77	10.88	11.79
Hot water extract of *T. minuta* @ 25 %	6.85	7.95	11.28	11.83
Hot water extract of *T. minuta* @ 30 %	5.44	7.93	11.46	11.86
Methanol extract of *T. minuta* @ 25 %	4.99	8.04	11.94	11.83
Methanol extract of *T. minuta* @ 30 %	4.92	7.87	10.77	11.90
Control (distilled water)	7.85		11.86	
CD (0.05)	0.24			

Table 27b. Interaction between time of application and allelopathic extracts on shoot length (cm) of green gram

Allelopathic extracts	Time of application			
	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing
	Observation at 7th day of sowing		Observation at 15th day of sowing	
Cold water extract of *A. paniculata* @ 25 %	6.33	7.36	11.78	10.74
Cold water extract of *A. paniculata* @ 30 %	5.98	7.42	11.61	10.81
Methanol extract of *A. paniculata* @ 25 %	5.43	7.41	11.48	10.86
Methanol extract of *A. paniculata* @ 30 %	5.18	7.54	10.82	10.78
Cold water extract of *T. minuta* @ 25 %	5.12	7.56	10.69	10.93
Cold water extract of *T. minuta* @ 30 %	4.76	7.40	10.56	10.73
Hot water extract of *T. minuta* @ 25 %	6.59	7.36	11.79	10.78
Hot water extract of *T. minuta* @ 30 %	5.36	7.43	11.22	10.79
Methanol extract of *T. minuta* @ 25 %	4.72	7.44	10.39	10.76
Methanol extract of *T. minuta* @ 30 %	4.65	7.51	10.31	10.85
Control (distilled water)	7.47		11.81	
CD (0.05)	0.15			

Table 27c. Interaction between time of application and allelopathic extracts on shoot length (cm) of rice

Allelopathic extracts	Time of application			
	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing
	Observation at 7th day of sowing		Observation at 15th day of sowing	
Cold water extract of *A. paniculata* @ 25 %	1.28	1.50	4.85	4.90
Cold water extract of *A. paniculata* @ 30 %	1.22	1.47	4.67	4.87
Methanol extract of *A. paniculata* @ 25 %	1.16	1.38	4.53	4.79
Methanol extract of *A. paniculata* @ 30 %	1.04	1.38	4.36	4.76
Cold water extract of *T. minuta* @ 25 %	1.03	1.49	4.25	4.97
Cold water extract of *T. minuta* @ 30 %	0.95	1.36	4.17	4.95
Hot water extract of *T. minuta* @ 25 %	1.29	1.29	4.88	4.90
Hot water extract of *T. minuta* @ 30 %	1.08	1.39	4.47	4.85
Methanol extract of *T. minuta* @ 25 %	0.92	1.47	3.98	4.89
Methanol extract of *T. minuta* @ 30 %	0.86	1.37	3.89	4.74
Control (distilled water)	1.47		4.90	
CD (0.05)	0.24			

b. Interaction between time of application and allelopathic extracts on root length of cowpea, green gram and rice

Root length of cowpea at 7 DAS and 15 DAS

Table 28a depicts the interaction effect of time of application and allelopathic extracts on the root length of cowpea.

Root length at 7 DAS

Allelopathic potential of treatments was more pronounced when applied on the same day of sowing. Lowest cowpea root growth was observed in the treatments applied on the day of sowing with 30 and 25 per cent methanol extract of *Tagetes minuta* (1.86 and 1.92 cm, respectively) and they were on par with 30 per cent cold water extract of same plant (2.04 cm). The root length in control treatment was 3.28 cm and was on par with treatments applied at 6 days after sowing.

Root length at 15 DAS

Lower root length of 4.71 cm, 4.78 cm and 4.81 cm were recorded in cowpea sprayed with 30 and 25 per cent methanol extract and 30 per cent cold water extract of *Tagetes minuta,* respectively which were applied on the day of sowing. Control treatment recorded a root length of 5.44 cm and was on par with treatments applied on 6^{th} day of sowing and also with 30 and 25 per cent of cold water extract of *Andrographis paniculata* and 25 per cent of hot water extract of *Tagetes minuta*.

Root length of green gram at 7 DAS and 15 DAS

Data on the combined effect of time of application and allelopathic extracts on root length of green gram is presented in the table 28b.

Root length at 7 DAS

Root suppression in green gram followed the same trend of cowpea. Root growth inhibition was much pronounced when 30 and 25 per cent *Tagetes minuta* methanol extracts were applied on the day of sowing (1.94 and 2.09 cm, respectively) and were on par with 30 per cent *Tagetes minuta* cold water aqueous extract (2.14 cm). Control treatment recorded root length of 3.32 cm.

Root length at 15 DAS

The treatments with 30 and 25 per cent *Tagetes minuta* methanol extracts applied on the same day of sowing recorded the lower root length of 4.84 cm and 4.93 cm. These were on par with cold water extract of 30 per cent *Tagetes minuta* (5.07 cm). The root length in control was 5.79 cm.

Root length of rice at 7 DAS and 15 DAS

Interaction between time of application and allelopathic extracts exhibited significant influence on root length of rice at 15 days after sowing (Table 28c).

Root length at 15 DAS

Among different treatments, 30 and 25 per cent *Tagetes minuta* methanol extract applied on the day of sowing had lower root length of 5.74 cm and 5.79 cm respectively which was on par with 30 and 25 per cent of cold water extract of *Tagetes minuta* (5.82 and 5.91 cm, respectively) and also with 30 per cent of methanol extract of *Andrographis paniculata* applied at on the day of sowing. Control treatment recorded root length of 6.63 cm and was statistically on par with all the treatments applied at 6th day of sowing and 25 per cent hot water extract of *Tagetes minuta* applied on the day of sowing.

Table 28a. Interaction between time of application and allelopathic extracts on root length (cm) of cowpea

Allelopathic extracts	Time of application			
	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing
	Observation at 7th day of sowing		Observation at 15th day of sowing	
Cold water extract of *A. paniculata* @ 25 %	2.68	3.18	5.52	5.48
Cold water extract of *A. paniculata* @ 30 %	2.57	3.17	5.41	5.46
Methanol extract of *A. paniculata* @ 25 %	2.45	3.28	5.37	5.42
Methanol extract of *A. paniculata* @ 30 %	2.20	3.29	5.10	5.39
Cold water extract of *T. minuta* @ 25 %	2.18	3.37	5.03	5.52
Cold water extract of *T. minuta* @ 30 %	2.04	3.20	4.81	5.48
Hot water extract of *T. minuta* @ 25 %	2.87	3.30	5.53	5.36
Hot water extract of *T. minuta* @ 30 %	2.27	3.35	5.21	5.40
Methanol extract of *T. minuta* @ 25 %	1.92	3.26	4.78	5.51
Methanol extract of *T. minuta* @ 30 %	1.86	3.30	4.71	5.45
Control (distilled water)	3.28		5.44	
CD (0.05)	0.24			

Table 28b. Interaction between time of application and allelopathic extracts on root length (cm) of green gram

Allelopathic extracts	Time of application			
	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing
	Observation at 7th day of sowing		Observation at 15th day of sowing	
Cold water extract of *A. paniculata* @ 25 %	2.94	3.36	5.66	5.78
Cold water extract of *A. paniculata* @ 30 %	2.73	3.26	5.59	5.86
Methanol extract of *A. paniculata* @ 25 %	2.37	3.33	5.54	5.83
Methanol extract of *A. paniculata* @ 30 %	2.23	3.35	5.46	5.77
Cold water extract of *T. minuta* @ 25 %	2.22	3.37	5.39	5.82
Cold water extract of *T. minuta* @ 30 %	2.14	3.43	5.07	5.75
Hot water extract of *T. minuta* @ 25 %	3.00	3.29	5.69	5.68
Hot water extract of *T. minuta* @ 30 %	2.50	3.34	5.47	5.77
Methanol extract of *T. minuta* @ 25 %	2.09	3.29	4.93	5.72
Methanol extract of *T. minuta* @ 30 %	1.94	3.40	4.84	5.65
Control (distilled water)	3.32		5.79	
CD (0.05)	0.24			

Table 28c. Interaction between time of application and allelopathic extracts on root length (cm) of rice

Allelopathic extracts	Time of application			
	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing
	Observation at 7th day of sowing		Observation at 15th day of sowing	
Cold water extract of *A. paniculata* @ 25 %	1.23	1.23	6.47	6.57
Cold water extract of *A. paniculata* @ 30 %	1.23	1.19	6.35	6.62
Methanol extract of *A. paniculata* @ 25 %	1.22	1.23	6.15	6.69
Methanol extract of *A. paniculata* @ 30 %	1.15	1.263	5.90	6.73
Cold water extract of *T. minuta* @ 25 %	1.11	1.24	5.91	6.71
Cold water extract of *T. minuta* @ 30 %	0.94	1.273	5.82	6.64
Hot water extract of *T. minuta* @ 25 %	1.26	1.25	6.56	6.59
Hot water extract of *T. minuta* @ 30 %	1.16	1.29	6.10	6.57
Methanol extract of *T. minuta* @ 25 %	0.89	1.26	5.79	6.66
Methanol extract of *T. minuta* @ 30 %	0.81	1.17	5.74	6.67
Control (distilled water)	1.23		6.63	
CD (0.05)	NS		0.24	

c. Interaction between time of application and allelopathic extracts on fresh weight of cowpea, green gram and rice

Fresh weight of cowpea at 7 and 15 DAS

Fresh weight of cowpea as influenced by interaction between time of application and allelopathic extracts was not significant on 7 days after sowing. However, interaction was significant at 15 days after sowing (Table 29a).

At 15 days after sowing maximum reduction in fresh weight of cowpea was observed in 30 and 25 per cent methanol extract of *Tagetes minuta* sprayed on the same days sowing and also on 6th day of sowing, Control treatment recorded a fresh weight of 0.482 g/plant.

Fresh weight of green gram at 7 and 15 DAS

Data on interaction between time of application and allelopathic extracts on fresh weight of green gram are presented in the Table 29b. Interaction was not significant with respect to fresh weight of green gram at 7 and 15 days after sowing.

Fresh weight of rice at 7 and 15 DAS

Table 29c depicts the combined effect of two factors on fresh weight of rice at 7 and 15 days of sowing. No significant interaction was observed with respect to fresh weight both at 7 days after sowing and 15 days after sowing.

Table 29a. Interaction between time of application and allelopathic extracts on fresh weight of cowpea (g/plant)

Allelopathic extracts	Observation at 7th day of sowing		Observation at 15th day of sowing	
	Time of application			
	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing
Cold water extract of *A. paniculata* @ 25 %	0.05	0.06	0.520	0.510
Cold water extract of *A. paniculata* @ 30 %	0.04	0.06	0.50	0.50
Methanol extract of *A. paniculata* @ 25 %	0.04	0.06	0.49	0.50
Methanol extract of *A. paniculata* @ 30 %	0.04	0.06	0.49	0.48
Cold water extract of *T. minuta* @ 25 %	0.04	0.06	0.49	0.49
Cold water extract of *T. minuta* @ 30 %	0.03	0.04	0.49	0.49
Hot water extract of *T. minuta* @ 25 %	0.05	0.04	0.49	0.49
Hot water extract of *T. minuta* @ 30 %	0.04	0.06	0.52	0.47
Methanol extract of *T. minuta* @ 25 %	0.03	0.06	0.44	0.45
Methanol extract of *T. minuta* @ 30 %	0.03	0.04	0.45	0.47
Control (distilled water)	0.06		0.48	
CD (0.05)	NS		0.02	

Table 29b. Interaction between time of application and allelopathic extracts on fresh weight of green gram (g/plant)

Allelopathic extracts	Observation at 7th day of sowing		Observation at 15th day of sowing	
	Time of application			
	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing
Cold water extract of *A. paniculata* @ 25 %	0.04	0.06	0.43	0.42
Cold water extract of *A. paniculata* @ 30 %	0.04	0.05	0.41	0.42
Methanol extract of *A. paniculata* @ 25 %	0.04	0.05	0.41	0.40
Methanol extract of *A. paniculata* @ 30 %	0.04	0.05	0.38	0.39
Cold water extract of *T. minuta* @ 25 %	0.04	0.05	0.40	0.41
Cold water extract of *T. minuta* @ 30 %	0.03	0.34	0.46	0.46
Hot water extract of *T. minuta* @ 25 %	0.04	0.04	0.45	0.42
Hot water extract of *T. minuta* @ 30 %	0.04	0.05	0.42	0.41
Methanol extract of *T. minuta* @ 25 %	0.04	0.05	0.40	0.38
Methanol extract of *T. minuta* @ 30 %	0.03	0.26	0.37	0.38
Control (distilled water)	0.06		0.41	
CD (0.05)	NS		NS	

Table 29c. Interaction between time of application and allelopathic extracts on fresh weight of rice (g/plant)

Allelopathic extracts	Observation at 7th day of sowing		Observation at 15th day of sowing	
	Time of application			
	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing
Cold water extract of *A. paniculata* @ 25 %	0.01	0.02	0.27	0.29
Cold water extract of *A. paniculata* @ 30 %	0.01	0.01	0.27	0.28
Methanol extract of *A. paniculata* @ 25 %	0.01	0.01	0.26	0.28
Methanol extract of *A. paniculata* @ 30 %	0.01	0.01	0.26	0.26
Cold water extract of *T. minuta* @ 25 %	0.01	0.01	0.26	0.28
Cold water extract of *T. minuta* @ 30 %	0.01	0.01	0.41	0.42
Hot water extract of *T. minuta* @ 25 %	0.01	0.01	0.27	0.28
Hot water extract of *T. minuta* @ 30 %	0.01	0.01	0.26	0.28
Methanol extract of *T. minuta* @ 25 %	0.01	0.01	0.26	0.27
Methanol extract of *T. minuta* @ 30 %	0.01	0.01	0.25	0.27
Control (distilled water)	0.02		0.27	
CD (0.05)	NS		NS	

4.3. Experiment 2 B. Pot culture study on allelopathic effect of plant extracts on weeds and test crops

4.3.1. Direct effect of treatments

A) Observations on weeds

Weed count at 3, 6, 12 and 25 DAS

Data on direct effect of allelopathic influence of treatments and time of application on weed count in cowpea, green gram and rice were presented in the tables 30a, 30b and 30c.

Weed count in cowpea at 3, 6, 12 and 25 DAS

Perusal of data on the direct influence of time of application of treatments on weed germination revealed the significant influence of time of application of extracts on weed count in cowpea at 3 and 6 DAS. However, the effect was not significant at 12 and 25 DAS.

At 3 DAS, the lowest weed count was observed when treatments were applied on the day of sowing (1.68 no./m^2). The treatments with application on 6^{th} day of sowing recorded a weed count of 14.31 no./m^2. At 6 DAS, lower weed count of 69.86 no./m^2 was found in treatments applied on the day of sowing and the highest count of 217.74 no./m^2 was in 6^{th} day sowing.

The influence of allelopathic extracts on weed germination was significant only at 6 DAS. Lower weed count of 125 no./m^2 was recorded from 30 and 25 per cent methanol extract of *Tagetes minuta* followed by *Andrographis paniculata* cold water extract at 30 per cent (129.63 no./m^2). At 6 DAS, germination count of weeds were higher in control treatment (203.70 no./m^2) followed by the 25 and 30 per cent hot water extracts of *Tagetes minuta* (148.15 no./m^2).

Weed count in green gram at 3, 6, 12 and 25 DAS

Data pertaining to the individual effect of time of application on germination count of weeds in green gram at 3 and 6 DAS exhibited significant difference, however, no significant influence was observed towards later stages.

At 3 DAS, lower weed germination was observed when treatments were applied on the day of sowing (1.68 no./m^2) than the application at 6^{th} day of sowing (13.47 no./m^2). At 6 DAS also, lowest weed count (68.18 no./m^2) was observed in on the day of sowing treatment as compared to treatment application at 6^{th} day of sowing (176.77 no./m^2).

Direct mean effect of allelopathic extracts on weed count of green gram was significant only at 6 DAS. The lowest weed count was observed from treatment applied with *Tagetes minuta* methanol extract at 30 per cent concentration (97.22 no./m^2) followed by 25 per cent methanol and 30 per cent aqueous extracts of *Tagetes minuta* (106.48 no./m^2). The highest weed germination count at 6 DAS was recorded from the control treatment (194.44 no./m^2).

Weed count in rice at 3, 6, 12 and 25 DAS

Significant influence of time of application on germination count of rice weeds was significant only at 3 and 6 DAS and non significant at 12 and 25 DAS. Lower weed count of 2.52 no./m^2 at 3 DAS and 95.12 no./m^2 at 6 DAS were observed when treatments were applied on the day of sowing as compared to the application at 6^{th} day of sowing.

Regarding direct effect of allelopathic extracts, weed count data were significant only at 6 DAS. At 3, 12 and 25 DAS treatments had no significant influence on weed germination in rice. Among treatments, germination count reduction was more prominent in 30 per cent methanol extract of *Tagetes minuta* (115.74 no./m^2) followed by 25 per cent of methanol extract of *Tagetes minuta* (120.37 no./m^2). Next lower weed counts were recorded in *Andrographis paniculata* methanol extract at 30 per cent (125 no./m^2). Control treatment recorded the highest germination count of 185.18 no./m^2. As compared to control treatment all treatments inhibited weed germination to some extent.

Weed dry weight in cowpea, green gram and rice at 25 DAS

Table 31 depicts the individual direct effect of time of application and allelopathic extracts on the dry weight of weeds in cowpea, green gram and rice at 25 DAS. Significant effect was observed for these two factors on weed dry weights.

Allelopathic extracts were more effective when applied on the day of sowing than the application on 6th day of sowing. Lower weed dry weights of 41.96 g/m^2, 31.82 g/m^2 and 48.18 g/m^2 were recorded in cowpea, green gram and rice when allelopathic extracts were applied on the same day of sowing. Weed dry weights in treatments which applied at 6th day of sowing were 51.68 g/m^2, 39.49 g/m^2 and 56.78 g/m^2 respectively in cowpea, green gram and rice.

With respect to effect of allelopathic extracts, maximum dry weight reduction in cowpea was observed in 30 and 25 per cent methanol extract of *Tagetes minuta* (34.13 and 37.82 g/m^2 respectively) and was on par with *Tagetes minuta* cold water extract at 30 and 25 per cent (40.33 and 41.67 g/m^2 respectively).

In green gram, lower weed dry weight of 26.54 g/m^2 and 28.66 g/m^2 were observed in treatments applied with methanol extract of *Tagetes minuta* at 30 and 25 per cent. As compared to control treatment, all the treatments except *Andrographis paniculata* cold water extract at 25 and 30 per cent and 25 per cent hot water extract of *Tagetes minuta* reduced weed dry weight significantly.

Table 30a. Weed count in cowpea at 3, 6, 12 and 25 DAS

	Weed count (No./m^2) - Cowpea			
	3 DAS	**6 DAS**	**12 DAS**	**25 DAS**
Time of application				
On the day of sowing	1.26 (1.68)	7.95 (69.86)	15.27 (233.15)	9.41 (89.22)
6th day of sowing	3.05 (14.31)	14.73 (217.74)	15.23 (231.48)	9.61 (94.28)
CD (0.05)	1.06	0.722	NS	NS
Allelopathic extracts				
Cold water extract of *A. paniculata* @ 25 %	1.73 (4.63)	11.56 (143.52)	15.36 (236.11)	9.61 (92.59)
Cold water extract of *A. paniculata* @ 30 %	1.73 (4.63)	10.90 (129.63)	15.69 (245.37)	9.18 (83.33)
Methanol extract of *A. paniculata* @ 25 %	1.73 (4.63)	11.35 (138.89)	15.09 (226.85)	9.37 (87.96)
Methanol extract of *A. paniculata* @ 30 %	2.45 (9.26)	11.15 (138.89)	15.38 (236.11)	9.81 (97.22)
Cold water extract of *T. minuta* @ 25 %	1.73 (4.63)	11.05 (134.26)	14.54 (212.96)	8.90 (83.33)
Cold water extract of *T. minuta* @ 30 %	2.09 (9.26)	11.09 (143.52)	15.24 (231.48)	9.37 (87.96)
Hot water extract of *T. minuta* @ 25 %	2.45 (9.26)	11.84 (148.15)	15.38 (236.11)	9.69 (97.22)
Hot water extract of *T. minuta* @ 30 %	2.09 (9.26)	11.66 (148.15)	15.23 (231.48)	9.26 (87.96)
Methanol extract of *T. minuta* @ 25 %	2.09 (9.26)	9.77 (125.00)	15.05 (226.85)	9.89 (97.22)
Methanol extract of *T. minuta* @ 30 %	1.73 (4.63)	10.12 (125.00)	15.22 (231.48)	9.43 (92.59)
Control (distilled water)	3.91 (18.52)	14.30 (203.70)	15.54 (240.74)	10.12 (101.85)
CD (0.05)	NS	2.40	NS	NS

** $\sqrt{x+0.5}$ transformed values, original values are given in parentheses

Table 30b. Weed count in green gram at 3, 6, 12 and 25 DAS

	Weed count (No./m^2) – Green gram			
	3 DAS	**6 DAS**	**12 DAS**	**25 DAS**
Time of application				
On the day of sowing	1.20 (1.68)	7.77 (68.18)	14.74 (217.17)	9.43 (89.22)
6th day of sowing	2.71 (13.47)	13.29 (176.77)	14.67 (215.49)	9.51 (90.91)
CD (0.05)	1.18	0.87	NS	NS
Allelopathic extracts				
Cold water extract of *A. paniculata* @ 25 %	2.09 (9.26)	11.41 (134.26)	14.46 (208.33)	9.46 (92.59)
Cold water extract of *A. paniculata* @ 30 %	2.09 (9.26)	10.62 (120.37)	14.56 (212.96)	9.65 (92.59)
Methanol extract of *A. paniculata* @ 25 %	1.73 (4.63)	10.30 (115.74)	14.78 (217.59)	9.58 (92.59)
Methanol extract of *A. paniculata* @ 30 %	2.09 (9.26)	10.02 (111.11)	14.58 (212.96)	9.86 (97.22)
Cold water extract of *T. minuta* @ 25 %	1.73 (4.63)	9.94 (111.11)	14.59 (212.96)	9.61 (92.59)
Cold water extract of *T. minuta* @ 30 %	1.00 (0.00)	9.79 (106.48)	15.08 (226.85)	9.18 (83.33)
Hot water extract of *T. minuta* @ 25 %	2.09 (9.26)	11.46 (134.26)	14.71 (217.59)	9.65 (92.59)
Hot water extract of *T. minuta* @ 30 %	1.73 (4.63)	10.30 (115.74)	14.46 (208.33)	9.42 (87.96)
Methanol extract of *T. minuta* @ 25 %	2.09 (9.26)	9.21 (106.48)	14.58 (212.96)	9.14 (83.33)
Methanol extract of *T. minuta* @ 30 %	1.73 (4.63)	8.77 (97.22)	14.72 (217.59)	8.97 (83.33)
Control (distilled water)	3.17 (18.52)	13.98 (194.44)	15.24 (231.48)	9.65 (92.59)
CD (0.05)	NS	2.03	NS	NS

** √x+0.5 transformed values, original values are given in parentheses

Table 30c. Weed count in rice at 3, 6, 12 and 25 DAS

	Weed count (No./m^2) - Rice			
	3 DAS	**6 DAS**	**12 DAS**	**25 DAS**
Time of application				
On the day of sowing	1.40 (2.52)	9.60 (95.12)	15.31 (234.01)	9.90 (99.33)
6th day of sowing	3.44 (17.68)	13.16 (173.40)	15.34 (234.85)	10.19 (105.22)
CD (0.05)	1.02	0.70	NS	NS
Allelopathic extracts				
Cold water extract of *A. paniculata* @ 25 %	2.09 (9.26)	11.40 (134.26)	15.38 (236.11)	9.81 (97.22)
Cold water extract of *A. paniculata* @ 30 %	2.09 (9.26)	11.56 (138.89)	15.22 (231.48)	10.09 (101.85)
Methanol extract of *A. paniculata* @ 25 %	2.05 (9.26)	11.26 (129.63)	15.37 (236.11)	9.89 (97.22)
Methanol extract of *A. paniculata* @ 30 %	2.81 (13.88)	11.02 (125.00)	15.21 (231.48)	10.49 (111.11)
Cold water extract of *T. minuta* @ 25 %	2.45 (9.26)	11.24 (129.63)	15.36 (236.11)	10.05 (101.85)
Cold water extract of *T. minuta* @ 30 %	1.00 (0.00)	11.13 (129.63)	14.93 (222.22)	10.33 (106.48)
Hot water extract of *T. minuta* @ 25 %	2.09 (9.26)	11.77 (138.89)	15.52 (240.74)	10.06 (101.85)
Hot water extract of *T. minuta* @ 30 %	2.45 (9.26)	11.25 (129.63)	15.39 (236.11)	9.77 (97.22)
Methanol extract of *T. minuta* @ 25 %	1.73 (4.63)	10.59 (120.37)	15.39 (236.11)	9.67 (111.11)
Methanol extract of *T. minuta* @ 30 %	2.09 (9.26)	10.32 (115.74)	14.92 (222.22)	9.74 (97.22)
Control (distilled water)	5.36 (27.78)	13.64 (185.18)	15.84 (250.00)	10.59 (111.11)
CD (0.05)	NS	1.65	NS	NS

** $\sqrt{x+0.5}$ transformed values, original values are given in parentheses

Table 31. Weed dry weight in cowpea, green gram and rice at 25 DAS

	Weed dry weight at 25 DAS (g/m^2)		
	Cowpea	**Green gram**	**Rice**
Time of application			
On the day of sowing	41.96	31.82	48.18
6^{th} day of sowing	51.68	39.49	56.78
CD (0.05)	3.26	5.16	2.80
Allelopathic extracts			
Cold water extract of *A. paniculata* @ 25 %	55.05	41.76	54.75
Cold water extract of *A. paniculata* @ 30 %	52.61	40.46	54.03
Methanol extract of *A. paniculata* @ 25 %	47.77	37.02	52.18
Methanol extract of *A. paniculata* @ 30 %	44.02	31.84	50.85
Cold water extract of *T. minuta* @ 25 %	41.67	31.56	50.82
Cold water extract of *T. minuta* @ 30 %	40.33	29.95	49.99
Hot water extract of *T. minuta* @ 25 %	55.88	42.49	55.98
Hot water extract of *T. minuta* @ 30 %	46.04	35.94	51.05
Methanol extract of *T. minuta* @ 25 %	37.82	28.66	48.82
Methanol extract of *T. minuta* @ 30 %	34.13	26.54	46.87
Control (distilled water)	59.68	45.97	61.92
CD (0.05)	7.64	12.10	6.57

B) Observation on crops

Germination count

Pre emergence application of extracts influenced the germination count of crops. However, post emergence application (at 6th day of sowing) exhibited no significant influence on germination count of crops (Table 32).

As compared to control, germination was delayed in cowpea due to application of allelopathic extracts. First seed germination was noticed on 8th day, with 5 days delay as compared to control treatment and was observed with 30 and 25 per cent of methanol extracts from *Tagetes minuta* plant. Only 7 and 9 seeds were germinated from total of 12 seeds when treated with 30 and 25 per cent of methanol extracts from *Tagetes minuta* plant respectively. Out of 12 seeds only 10 seedlings were recorded on treatment with 30 per cent of aqueous extraction of *Tagetes minuta*.

Same trend was followed in green gram. Green gram seed germination delay was about 5 days compared to control treatment. Highest allelopathic treatment effect of 30 and 25 per cent of methanol extracts from *Tagetes minuta* resulted in inhibition of 5 seeds and 2 seeds, respectively.

As compared to cowpea and green gram, seeds of rice were not much influenced by the treatment application. Only 3 seeds were inhibited from total of 12 seeds with application of 30 per cent of methanol extraction from *Tagetes minuta*.

Table 32. Germination counts of cowpea, green gram and rice

	Total germinated seeds (No.)		
	Cowpea	**Green gram**	**Rice**
Allelopathic extracts			
Cold water extract of *A. paniculata* @ 25 %	12	12	12
Cold water extract of *A. paniculata* @ 30 %	12	12	12
Methanol extract of *A. paniculata* @ 25 %	12	12	12
Methanol extract of *A. paniculata* @ 30 %	12	12	12
Cold water extract of *T. minuta* @ 25 %	12	12	12
Cold water extract of *T. minuta* @ 30 %	10	11	12
Hot water extract of *T. minuta* @ 25 %	12	12	12
Hot water extract of *T. minuta* @ 30 %	12	12	12
Methanol extract of *T. minuta* @ 25 %	9	9	12
Methanol extract of *T. minuta* @ 30 %	7	7	9
Control (distilled water)	12	12	12

Visual symptoms of phytotoxicity on 3rd and 7th day after spraying

No visual phytotoxicity symptoms were noticed on cowpea, green gram and rice at 3rd and 7th day after spraying.

Shoot length of cowpea, green gram and rice at one month after sowing

Data pertaining to the effect of time of application and allelopathic extracts on the shoot length of cowpea, green and rice were are in Table 33. The direct effect of both factors had significant influence on the shoot length of cowpea, green gram and rice.

Lower shoot lengths of 22.58 cm, 18.75 cm and 9.57 cm, respectively in cowpea, green gram and rice were recorded when treatments were applied on the day of sowing of crops. Shoot lengths in treatments applied on 6th day of sowing were 28.57 cm in cowpea, 25.46 cm in green gram and 10.37 cm in rice.

Among allelopathic extracts, more shoot length suppression of 21.62 cm in cowpea, and 18.58 cm in green gram was observed when crops were applied with 30 per cent methanol extract of *Tagetes minuta* followed by 25 per cent methanol extract (23.09 cm for cowpea and 18.84 cm green gram). In the case of rice, lowest shoot length of 9.61 cm was observed with 30 per cent methanol and hot water extract of *Tagetes minuta*.

Normal growth and higher shoot length of cowpea (28.90 cm), green gram (25.90 cm) and rice (10.30 cm) were observed in control treatment.

Root length of cowpea, green gram and rice at one month after sowing

Direct influence of time of application and allelopathic extracts exhibited statistical significance on the root length of cowpea, green gram and rice (Table 34).

As in the case of shoot length, root length also showed significant reduction when extracts were sprayed on the day of sowing. Lower root lengths of 6.02 cm and 5.32 cm in cowpea and green gram were recorded when seeds were treated with extracts on the day of sowing. Higher root growth in cowpea (10.60 cm) and green gram (7.87

cm) were noticed when treatment application was done at 6th day of sowing. However, for rice, the time of application had no significant influence with respect to root length.

Root length reduction based on the effects of allelopathic extracts followed same trends for cowpea, green gram and rice. Methanol extract of *Tagetes minuta* at 30 per cent reduced cowpea (6.85 cm) and green gram (5.05 cm) root lengths significantly. They were followed by 25 per cent methanol and 30 and 25 per cent cold water extracts of *Tagetes minuta* in cowpea (7.10, 7.15 and 7.22 cm, respectively). Lower green gram root length of 5.29 cm recorded from 25 per cent *Tagetes minuta* methanol extract. Higher root length of 10.60 cm and 7.90 cm respectively for cowpea and green gram were recorded from control treatment. Lower root length of rice seedlings was also observed in 30 and 25 per cent of *Tagetes minuta* methanol extracts (18.39 and 18.46 cm, respectively).

Table 33. Shoot length of cowpea, green gram and rice at one month after sowing

	Shoot length (cm)		
	Cowpea	**Green gram**	**Rice**
Time of application			
On the day of sowing	22.58	18.75	9.57
6th day of sowing	28.57	25.46	10.37
CD (0.05)	0.07		
Allelopathic extracts			
Cold water extract of *A. paniculata* @ 25 %	28.14	24.48	10.20
Cold water extract of *A. paniculata* @ 30 %	27.12	24.39	9.99
Methanol extract of *A. paniculata* @ 25 %	26.77	23.23	10.31
Methanol extract of *A. paniculata* @ 30 %	24.69	20.93	10.23
Cold water extract of *T. minuta* @ 25 %	23.72	20.28	9.74
Cold water extract of *T. minuta* @ 30 %	23.49	19.98	9.75
Hot water extract of *T. minuta* @ 25 %	28.42	24.70	9.82
Hot water extract of *T. minuta* @ 30 %	25.38	21.85	9.61
Methanol extract of *T. minuta* @ 25 %	23.09	18.84	9.95
Methanol extract of *T. minuta* @ 30 %	21.62	18.58	9.61
Control (distilled water)	28.90	25.90	10.30
CD (0.05)	0.17		

Table 34. Root length of cowpea, green gram and rice at one month after sowing

	Root length (cm)		
	Cowpea	**Green gram**	**Rice**
Time of application			
On the day of sowing	6.02	5.32	17.39
6th day of sowing	10.60	7.87	18.97
CD (0.05)	0.07		NS
Allelopathic extracts			
Cold water extract of *A. paniculata* @ 25 %	9.12	7.30	19.16
Cold water extract of *A. paniculata* @ 30 %	8.87	7.28	19.16
Methanol extract of *A. paniculata* @ 25 %	8.39	7.12	19.04
Methanol extract of *A. paniculata* @ 30 %	7.97	6.50	19.03
Cold water extract of *T. minuta* @ 25 %	7.22	5.99	18.75
Cold water extract of *T. minuta* @ 30 %	7.15	5.91	18.63
Hot water extract of *T. minuta* @ 25 %	9.73	7.42	19.27
Hot water extract of *T. minuta* @ 30 %	8.39	6.81	19.06
Methanol extract of *T. minuta* @ 25 %	7.10	5.29	18.46
Methanol extract of *T. minuta* @ 30 %	6.85	5.05	18.39
Control (distilled water)	10.60	7.90	19.30
CD (0.05)	0.17		

Fresh weight of cowpea, green gram and rice at one month after sowing

Greater allelopathic potential was noticed when treatments were applied on the day of sowing. Lower fresh weights of 25.94 g/plant for cowpea, 22.06 g/plant for green gram and 10.67 g/plant for rice were observed when treatments were applied on the day of sowing (Table 35). Fresh weights in cowpea, green gram and rice when treated with extracts on 6th day of sowing were 27.02 g/plant, 22.84 g/plant and 11.35 g/plant respectively.

Regarding direct influence of allelopathic extracts, lower cowpea fresh weight of 22.94 g/plant was recorded from 30 per cent methanol extract of *Tagetes minuta* followed by 25 per cent methanol and 30 per cent cold water extracts of *Tagetes minuta* (24.35 and 24.49 g/plant, respectively). For green gram, lower fresh weight was observed with 30 per cent *Tagetes minuta* methanol extract (17.77 g/plant) followed by its 25 per cent methanol (18.92 g/plant) and 30 per cent cold water (19.21 g/plant) extracts of *Tagetes minuta*. In rice, 30 and 25 per cent methanol and 30 per cent cold water extract of *Tagetes minuta* recorded lower fresh weight (8.35, 9.30 and 9.81 g/plant, respectively). Higher fresh weights of 29.47g/plant, 25.28 g/plant and 13.09 g/plant respectively in cowpea, green gram and rice were observed in control treatment.

Dry weight of cowpea, green gram and rice at one month after sowing

The data on the direct effect of time of application and allelopathic extracts on dry weight of cowpea, green gram and rice exhibited significant differences (Table 36).

Regarding time of application, dry weight reduction was more when treatments applied on the day of sowing compared to application at 6th day of sowing. Lower dry weight values for cowpea, green gram and rice (8.41 g/plant, 7.53 g/plant and 3.80 g/plant, respectively) were noticed when treatments were applied on the day of sowing. Dry weights in treatments which were applied on the 6th day of sowing were 9.57 g/plant in cowpea, 8.41 g/plant in green gram and 4.48 g/plant in rice.

Lower dry weight of 5.39 g/plant was observed in cowpea treated with 30 per cent *Tagetes minuta* methanol extract and was on par with all the treatments except 25

per cent and methanol extract (6.45 g/plant) and 30 per cent cold water extract (7.03 g/plant) of *Tagetes minuta*. For green gram, lower dry weight were in *Tagetes minuta* 30 and 25 per cent methanol extract (4.93 and 5.19 g/plant, respectively) followed by 30 and 25 per cent cold water extract (6.57 and 7.82 g/plant, respectively) of *Tagetes minuta*.

The lowest dry weight of rice was recorded with *Tagetes minuta* 30 per cent methanol extract (3.53 g/plant) and was on par with all treatments except 25 and 30 per cent of hot water extract of *Tagetes minuta.* Highest dry weights of cowpea, green gram and rice (12.01 g/plant, 10.65 g/plant and 6.22 g/plant, respectively) were in control.

Table 35. Fresh weight of cowpea, green gram and rice at one month after sowing

	Fresh weight (g/plant)		
	Cowpea	**Green gram**	**Rice**
Time of application			
On the day of sowing	25.94	22.06	10.67
6th day of sowing	27.02	22.84	11.35
CD (0.05)	0.64		
Treatments			
Cold water extract of *A. paniculata* @ 25 %	28.03	24.56	11.60
Cold water extract of *A. paniculata* @ 30 %	26.98	22.90	11.51
Methanol extract of *A. paniculata* @ 25 %	26.29	22.79	11.28
Methanol extract of *A. paniculata* @ 30 %	27.08	22.75	11.04
Cold water extract of *T. minuta* @ 25 %	27.23	22.55	11.04
Cold water extract of *T. minuta* @ 30 %	24.49	19.21	9.81
Hot water extract of *T. minuta* @ 25 %	29.35	25.15	12.17
Hot water extract of *T. minuta* @ 30 %	28.18	25.64	11.86
Methanol extract of *T. minuta* @ 25 %	24.35	18.92	9.30
Methanol extract of *T. minuta* @ 30 %	22.94	17.56	8.35
Control (distilled water)	29.47	25.28	13.09
CD (0.05)	1.27		

Table 36. Dry weight of cowpea, green gram and rice at one month after sowing

	Dry weight (g/plant)		
	Cowpea	**Green gram**	**Rice**
Time of application			
On the day of sowing	8.41	7.53	3.80
6th day of sowing	9.57	8.41	4.48
CD (0.05)	0.64		
Treatments			
Cold water extract of *A. paniculata* @ 25 %	10.57	9.93	4.73
Cold water extract of *A. paniculata* @ 30 %	9.78	8.15	4.64
Methanol extract of *A. paniculata* @ 25 %	9.63	8.11	4.41
Methanol extract of *A. paniculata* @ 30 %	9.53	8.26	4.39
Cold water extract of *T. minuta* @ 25 %	8.83	7.82	4.17
Cold water extract of *T. minuta* @ 30 %	7.03	6.57	3.48
Hot water extract of *T. minuta* @ 25 %	11.90	11.01	5.30
Hot water extract of *T. minuta* @ 30 %	10.72	10.51	4.99
Methanol extract of *T. minuta* @ 25 %	6.45	5.19	3.94
Methanol extract of *T. minuta* @ 30 %	5.39	4.93	3.53
Control (distilled water)	12.01	10.65	6.22
CD (0.05)	1.27		

4.3.2. Two factor interaction

Interaction between time of application and allelopathic extracts

4.3.2.1. Observations on weeds

Weed count in cowpea, green gram and rice at 3, 6, 12 and 25 DAS

The interaction effect of allelopathic extracts and time of application on the germination count of weeds in cowpea, green gram and rice at 3, 6, 12 and 25 DAS are presented in the tables 37a, 37b and 37c. Germination count of weeds was significant at 3 and 6 DAS in cowpea and green gram while in rice it was significant only at 3 DAS.

Weed count in cowpea 3 and 6 DAS

When allelopathic extracts were applied on the day of sowing, significant reduction in the number of weeds germinated was observed. Weed count in pots applied with extracts on the day of sowing was zero as compared to 21.52 no./m^2 in control treatment. Significant reduction in weed count was also observed in treatments with 30 and 25 per cent methanol extracts of *Tagetes minuta* and in 25 per cent cold water extract of *Andrographis paniculata* (9.26 no./m^2).

At 6 DAS, the lower weed count of 27.78 no./m^2 was observed in 30 and 25 per cent methanol extracts of *Tagetes minuta*. As compared to control, all the treatments with allelopathic extracts applied on the same day of sowing recorded significantly lower weed count. All the treatments which received treatment application at 6 DAS, except 30 per cent cold water extract of *Andrographis paniculata* was on par with control. In the control treatment the weed count was 203.70 no./m^2.

Weed count in green gram at 3 and 6 DAS

All the treatments applied with allelopathic extracts on the day sowing significantly controlled germination of weeds in green gram at 3 DAS. No weeds were observed in these treatments. 30 and 25 per cent methanol extracts of *Tagetes minuta* and 25 per cent cold water extract of *Andrographis paniculata* applied on 6^{th} day of sowing also reduced the weed count as compared to control, which recorded a weed count of 19.00 no./m^2.

At 6 days also lower weed count was observed when treatments were applied on the day of sowing.

Tagetes minuta 30 per cent methanol extract recorded a weed count of 27.78 no./m^2 as compared to 194.44 no./m^2 in control. Treatments applied on the 6^{th} day of sowing were on par with control treatment.

Weed count in rice at 3 DAS

In rice also, interaction was significant only at 3 DAS. Treatments which received application of allelopathic extracts on the day of sowing considerably reduced the germination count of weeds as compared to control and also those which received application of extracts on 6^{th} day of sowing. When allelopathic extracts were applied on the day of sowing germination count of weeds were zero as compared to 27.78 no./m^2 in control. Methanol extract of *Tagetes minuta* at 30 per cent when applied on 6^{th} day of sowing significantly reduced weed as compared to control. All other treatments applied on 6^{th} day were on par with control.

Weed dry weight in cowpea, green gram and rice at 25 DAS

Perusal of data presented in Table 38 clearly indicated the allelopathic effect of extracts and its time of application on reducing weed dry weight in cowpea, green gram and rice. All the treatments applied on the day of sowing significantly reduced the weed dry weight as compared to control treatment. Methanol extract of *Tagetes minuta* at 30 and 25 per cent applied on 6^{th} day of sowing effectively reduced weed dry weights in cowpea and green gram. Lower weed dry weights of 31.13 g/m^2, 22.45 g/m^2 and 41.69 g/m^2 respectively in cowpea, green gram and rice were observed in *Tagetes minuta* 30 per cent methanol extract applied on the day of sowing.

Table 37a. Interaction effect of time of application and allelopathic extracts on weed count in cowpea

Treatments	Weed count in cowpea (No./m^2)							
	Time of application							
	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing
	3 DAS		6 DAS		12 DAS		25 DAS	
Cold water extract of *A. paniculata* @ 25 %	1.00 (0.00)	4.30 (18.52)	8.54 (74.07)	14.58 (212.96)	15.84 (250.00)	14.88 (222.22)	9.10 (83.33)	10.12 (101.85)
Cold water extract of *A. paniculata* @ 30 %	1.00 (0.00)	3.04 (9.26)	7.82 (64.81)	13.98 (194.44)	15.84 (250)	15.54 (240.74)	9.18 (83.33)	9.18 (83.33)
Methanol extract of *A. paniculata* @ 25 %	1.00 (0.00)	4.06 (16.52)	8.07 (64.81)	14.62 (212.96)	15.24 (231.48)	14.94 (222.220	9.10 (83.33)	9.65 (92.59)
Methanol extract of *A. paniculata* @ 30 %	1.00 (0.00)	4.53 (20.52)	7.36 (55.55)	14.94 (222.22)	15.53 (240.74)	15.24 (231.48)	9.65 (92.59)	9.98 (101.85)
Cold water extract of *T. minuta* @ 25 %	1.00 (0.00)	3.50 (12.25)	7.52 (55.55)	14.58 (212.96)	14.79 (222.22)	14.30 (203.70)	8.85 (83.33)	8.96 (83.33)
Cold water extract of *T. minuta* @ 30 %	1.00 (0.00)	4.30 (18.52)	6.64 (46.30)	15.54 (240.74)	15.24 (231.48)	15.24 (231.48)	9.18 (83.33)	9.57 (92.59)
Hot water extract of *T. minuta* @ 25 %	1.00 (0.00)	4.03 (16.25)	9.18 (83.33)	14.50 (212.96)	14.92 (222.22)	15.84 (250)	10.12 (101.85)	9.26 (92.59)
Hot water extract of *T. minuta* @ 30 %	1.00 (0.00)	4.53 (20.52)	8.07 (64.81)	15.24 (231.48)	14.92 (222.22)	15.54 (240.74)	8.54 (74.07)	9.98 (101.85)
Methanol extract of *T. minuta* @ 25 %	1.00 (0.00)	3.04 (9.26)	4.63 (27.78)	14.92 (222.22)	14.88 (222.22)	15.22 (231.48)	9.65 (92.59)	10.12 (101.85)
Methanol extract of *T. minuta* @ 30 %	1.00 (0.00)	3.04 (9.26)	5.36 (27.78)	14.88 (222.22)	15.21 (231.48)	15.24 (231.48)	10.07 (101.85)	8.79 (83.33)
Control (distilled water)	4.74 (21.52)		14.30 (203.70)		15.54 (240.74)		10.12 (101.85)	
CD (0.05)	1.34		2.40		NS		NS	

** √x+0.5 transformed values, original values are given in parentheses

Table 37b. Interaction effect of time of application and allelopathic extracts on weed count in green gram

Weed count in green gram (No./m^2)								
Treatments	**Time of application**							
	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing
	3 DAS		**6 DAS**		**12 DAS**		**25 DAS**	
Cold water extract of *A. paniculata* @ 25 %	1.00 (0.00)	3.17 (18.52)	9.18 (83.33)	13.64 (185.18)	14.30 (203.70)	14.62 (212.96)	8.85 (83.33)	10.06 (101.85)
Cold water extract of *A. paniculata* @ 30 %	1.00 (0.00)	2.45 (9.26)	8.07 (64.81)	13.17 (175.92)	14.62 (212.96)	14.50 (212.96)	9.18 (83.33)	10.12 (101.85)
Methanol extract of *A. paniculata* @ 25 %	1.00 (0.00)	3.17 (18.52)	7.36 (55.55)	13.29 (175.92)	14.94 (222.22)	14.62 (212.96)	9.65 (92.59)	9.51 (92.59)
Methanol extract of *A. paniculata* @ 30 %	1.00 (0.00)	3.17 (18.52)	6.80 (46.30)	13.24 (175.92)	14.58 (212.96)	14.58 (212.96)	10.06 (101.85)	9.65 (92.59)
Cold water extract of *T. minuta* @ 25 %	1.00 (0.00)	3.17 (18.52)	6.64 (46.30)	13.24 (175.92)	14.88 (222.22)	14.30 (203.70)	10.12 (101.85)	9.10 (83.33)
Cold water extract of *T. minuta* @ 30 %	1.00 (0.00)	3.17 (18.52)	6.64 (46.30)	12.95 (166.67)	14.92 (222.22)	15.24 (231.48)	9.18 (83.33)	9.18 (83.33)
Hot water extract of *T. minuta* @ 25 %	1.00 (0.00)	3.17 (18.52)	9.65 (92.59)	13.26 (175.92)	14.92 (222.22)	14.50 (212.96)	9.18 (83.33)	10.12 (101.85)
Hot water extract of *T. minuta* @ 30 %	1.00 (0.00)	3.17 (18.52)	7.36 (55.55)	13.24 (175.92)	14.62 (212.96)	14.30 (203.70)	9.65 (92.59)	9.18 (83.33)
Methanol extract of *T. minuta* @ 25 %	1.00 (0.00)	2.45 (9.26)	5.18 (37.04)	13.24 (175.92)	14.58 (212.96)	14.58 (212.96)	9.10 (83.33)	9.18 (83.33)
Methanol extract of *T. minuta* @ 30 %	1.00 (0.00)	2.45 (9.26)	4.63 (27.78)	12.92 (166.67)	14.50 (212.96)	14.94 (222.22)	9.10 (83.33)	8.85 (83.33)
Control (distilled water)	4.47 (19.00)		13.98 (194.44)		15.24 (231.48)		9.65 (92.59)	
CD (0.05)	1.38		2.87		NS		NS	

** √x+0.5 transformed values, original values are given in parentheses

Table 37c. Interaction between time of application and allelopathic extracts on weed count in rice

Weed count in rice (No./m^2)								
Allelopathic extracts	**Time of application**							
	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing
	3 DAS		**6 DAS**		**12 DAS**		**25 DAS**	
Cold water extract of *A. paniculata* @ 25 %	1.00 (0.00)	3.17 (18.52)	9.88 (101.85)	12.92 (166.67)	15.22 (231.48)	15.38 (240.74)	10.12 (101.85)	9.51 (92.59)
Cold water extract of *A. paniculata* @ 30 %	1.00 (0.00)	3.17 (18.52)	9.88 (101.85)	13.24 (175.93)	15.52 (240.74)	15.22 (222.22)	10.53 (111.11)	9.65 (92.59)
Methanol extract of *A. paniculata* @ 25 %	1.00 (0.00)	3.91 (18.52)	9.65 (92.59)	12.86 (166.67)	14.92 (222.22)	15.37 (250)	10.59 (111.11)	9.18 (83.33)
Methanol extract of *A. paniculata* @ 30 %	1.00 (0.00)	4.63 (27.78)	9.18 (83.33)	12.85 (166.67)	15.22 (231.48)	15.21 (231.48)	9.98 (101.85)	11.00 (120.37)
Cold water extract of *T. minuta* @ 25 %	1.00 (0.00)	3.91 (18.51)	9.18 (83.33)	13.29 (175.93)	15.51 (240.74)	15.36 (231.48)	9.51 (92.59)	10.59 (111.11)
Cold water extract of *T. minuta* @ 30 %	1.00 (0.00)	3.17 (18.52)	8.63 (74.07)	13.64 (185.18)	14.92 (222.22)	14.93 (222.22)	9.65 (92.59)	11.00 (120.37)
Hot water extract of *T. minuta* @ 25 %	1.00 (0.00)	3.17 (18.52)	10.59 (111.11)	12.95 (166.67)	15.54 (240.74)	15.52 (240.74)	9.18 (83.33)	10.95 (120.37)
Hot water extract of *T. minuta* @ 30 %	1.00 (0.00)	3.91 (18.52)	9.65 (92.59)	12.85 (166.67)	15.24 (231.48)	15.39 (240.74)	9.57 (92.59)	9.98 (101.85)
Methanol extract of *T. minuta* @ 25 %	1.00 (0.00)	3.17 (18.52)	7.91 (64.81)	13.26 (175.93)	15.54 (240.74)	15.39 (231.48)	9.67 (101.85)	9.67 (101.85)
Methanol extract of *T. minuta* @ 30 %	1.00 (0.00)	2.45 (9.26)	7.36 (55.55)	13.29 (175.93)	14.92 (222.22)	14.92 (222.22)	9.51 (92.59)	9.98 (101.85)
Control (distilled water)	5.36 (27.78)		13.64 (185.18)		15.84 (250.00)		10.59 (111.11)	
CD (0.05)	2.54		NS		NS		NS	

** √x+0.5 transformed values, original values are given in parentheses

Table 38. Interaction between time of application and allelopathic extracts on weed dry weight from cowpea, green gram and rice

Weed dry weight at 25 DAS (g/m^2)						
Allelopathic extracts	**Time of application**					
	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing
	Cowpea		**Green gram**		**Rice**	
Cold water extract of *A. paniculata* @ 25 %	49.00	58.72	30.56	43.97	48.85	60.66
Cold water extract of *A. paniculata* @ 30 %	48.73	56.50	30.22	41.69	48.85	59.21
Methanol extract of *A. paniculata* @ 25 %	42.03	53.50	31.55	38.49	47.83	56.53
Methanol extract of *A. paniculata* @ 30 %	37.56	50.48	26.54	37.13	46.80	54.89
Cold water extract of *T. minuta* @ 25 %	33.85	49.50	27.57	35.55	46.80	54.83
Cold water extract of *T. minuta* @ 30 %	32.83	47.82	25.52	34.38	45.78	54.20
Hot water extract of *T. minuta* @ 25 %	42.59	59.17	32.62	47.35	48.90	61.06
Hot water extract of *T. minuta* @ 30 %	39.50	52.59	26.54	45.33	46.80	55.29
Methanol extract of *T. minuta* @ 25 %	32.27	43.37	23.48	33.85	43.74	53.90
Methanol extract of *T. minuta* @ 30 %	31.13	37.13	22.45	30.63	41.69	52.05
Control (distilled water)	59.68		45.97		61.92	
CD (0.05)	10.54		11.34		12.54	

4.3.2.2. Observation on crops

Shoot length of cowpea, green gram and rice at one month after sowing

Interaction effect of time of application and allelopathic extracts on shoot length of cowpea, green gram and rice are presented in the Table 39. Data showed significant differences.

In cowpea, lower shoot length of 14.49 cm was recorded from *Tagetes minuta* methanol extract at 30 per cent followed by *Tagetes minuta* methanol extract at 25 per cent concentration (17.67 cm) which were applied on the day of sowing. Higher shoot length of 28.90 cm was observed in control treatment and was on par with treatments applied at 6th day of sowing.

For green gram shoot length reduction was more pronounced in 30 per cent methanol extract of *Tagetes minuta* applied on the day of sowing (11.59 cm) followed 25 per cent methanol extract of *Tagetes minuta* (12.17 cm) applied on the same day. Higher shoot length of 25.90 cm was recorded in control treatment.

In the case of rice, seeds which received hot water and methanol extracts of *Tagetes minuta* at 30 per cent applied on the day of sowing (8.77 and 8.89 cm, respectively) recorded lower shoot growth. Shoot length of 9.11 cm was observed in 30 per cent cold water extract and shoot length of 9.24 cm in hot water extract of *Tagetes minuta* at 25 per cent which were applied on the day of sowing and was on par among themselves. Control treatment recorded shoot length of 10.30 cm and was on par with all the treatments applied on 6th day of sowing.

Table 39. Interaction between time of application and allelopathic extracts on shoot length of cowpea, green gram and rice at one month after sowing

Shoot length (cm)						
Allelopathic extracts	**Time of application**					
	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing
	Cowpea		**Green gram**		**Rice**	
Cold water extract of *A. paniculata* @ 25 %	27.74	28.53	23.64	25.32	9.94	10.47
Cold water extract of *A. paniculata* @ 30 %	25.58	28.66	23.38	25.41	9.58	10.40
Methanol extract of *A. paniculata* @ 25 %	25.04	28.50	21.04	25.43	10.24	10.39
Methanol extract of *A. paniculata* @ 30 %	20.93	28.45	16.43	25.43	10.03	10.43
Cold water extract of *T. minuta* @ 25 %	19.17	28.28	15.47	25.09	9.47	10.01
Cold water extract of *T. minuta* @ 30 %	18.41	28.57	14.51	25.44	9.11	10.39
Hot water extract of *T. minuta* @ 25 %	28.24	28.61	23.94	25.47	9.24	10.41
Hot water extract of *T. minuta* @ 30 %	22.27	28.49	18.17	25.53	8.77	10.44
Methanol extract of *T. minuta* @ 25 %	17.67	28.52	12.17	25.52	9.67	10.24
Methanol extract of *T. minuta* @ 30 %	14.49	28.76	11.59	25.57	8.89	10.33
Control (distilled water)	28.90		25.90		10.30	
CD (0.05)	0.24					

Root length of cowpea, green gram and rice at one month after sowing

Data on the interaction of time of application and allelopathic extracts on the root length of cowpea, green gram and rice are presented in Table 40. Combined effect of both factors was significant on root length of cowpea and green gram but not for root length of rice.

Root length of cowpea was lower in *Tagetes minuta* methanol extract at 30 per cent concentration (3.09 cm) followed by 25 per cent *Tagetes minuta* methanol extract (3.67 cm) and 30 and 25 per cent *Tagetes minuta* cold water extracts (3.87 and 3.91 cm, respectively) all applied on the day of sowing. Root length in control was 10.60 cm and was on par with treatments applied on 6^{th} day of sowing.

Lower root length of green gram (2.29 cm) was recorded from *Tagetes minuta* methanol extract at 30 per cent concentration applied on the same day of sowing followed by same treatment applied at 25 per cent concentration (2.67 cm). Control recorded a root length of 7.90 cm.

Table 40. Interaction between time of application and allelopathic extracts on root length of cowpea, green gram and rice at one month after sowing

Root length (cm)						
Allelopathic extracts	**Time of application**					
	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing
	Cowpea		**Green gram**		**Rice**	
Cold water extract of *A. paniculata* @ 25 %	7.74	10.50	6.64	7.96	19.22	19.11
Cold water extract of *A. paniculata* @ 30 %	7.18	10.56	6.48	8.09	19.24	19.08
Methanol extract of *A. paniculata* @ 25 %	6.24	10.54	6.24	8.00	19.11	18.98
Methanol extract of *A. paniculata* @ 30 %	5.13	10.81	5.13	7.86	19.15	18.90
Cold water extract of *T. minuta* @ 25 %	3.91	10.43	4.17	7.66	18.60	18.90
Cold water extract of *T. minuta* @ 30 %	3.87	10.53	4.11	7.86	18.67	18.58
Hot water extract of *T. minuta* @ 25 %	8.84	10.62	7.04	7.80	19.34	19.20
Hot water extract of *T. minuta* @ 30 %	5.97	10.81	5.87	7.75	19.14	18.98
Methanol extract of *T. minuta* @ 25 %	3.67	10.54	2.67	7.91	18.48	18.44
Methanol extract of *T. minuta* @ 30 %	3.09	10.62	2.29	7.81	18.43	18.35
Control (distilled water)	10.60		7.90		19.30	
CD (0.05)	0.24				NS	

Fresh weight of cowpea, green gram and rice at one month after sowing

Interaction effect of time of application and allelopathic extracts on the fresh weight of cowpea, green gram and rice are presented in the Table 41. The test crops exhibited significant difference in their fresh weight at one month after sowing.

Application of methanol extract of *Tagetes minuta* at 30 per cent concentration on the day of sowing reduced the fresh weight of cowpea to 22.38 g/plant as compared to 29.47 g/plant in control. It was followed by 25 per cent methanol extract of *Tagetes minuta* applied at on the day of sowing (24.53 g/plant) and cold water extract of *Tagetes minuta* at 30 and 25per cent concentration at on the day of sowing (25.04 and 25.28 g/plant, respectively).

In green gram at one month after sowing, lowest fresh weight was recorded when methanol extract of *Tagetes minuta* at 30 per cent concentration was applied on the day of sowing (18.10 g/plant) followed by application of 25 per cent of same treatment on the day of sowing (20.26 g/plant) and was on par with fresh weight of 20.53 g/plant and 21.08 g/pant were recorded in cold water extract of *Tagetes minuta* at 30 and 25 per cent concentration applied on the day of sowing respectively. In control fresh weight of green gram was 25.28 g/plant.

Lowest fresh weight from rice (8.52 g/plant) was recorded in the treatment 30 per cent methanol extract of *Tagetes minuta* applied on the day of sowing on par with *Tagetes minuta* methanol extract at 25 per cent (9.37 g/plant) and *Tagetes minuta* cold water extract 30 and 25 per cent applied at on the day of sowing (9.71 and 9.98 g/plant, respectively). Fresh weight in control treatment was 13.09 g/plant and was on par with all the treatments applied at 6th day of sowing except 25 per cent hot water extract of *Tagetes minuta*.

Dry weight of cowpea, green gram and rice at one month after sowing

The data depicted in Table 42 shows the dry weight of cowpea, green gram and rice at one month after sowing as influenced by interaction between allelopathic extracts and their time of application.

Lower dry weight for cowpea at one month after application (5.93 and 7.08 g/plant, respectively) was observed when treatments were applied on the day of sowing with 30 and 25 per cent of methanol extract of *Tagetes minuta* followed by *Tagetes minuta* 25 and 30 per cent cold water extract (7.59 and 7.83 g/plant, respectively) applied on the same day of sowing. Cowpea dry weight in control treatment was 12.01 g/plant and was on par with all the treatments applied at 6th day of sowing.

Same trend was observed for green gram also. Fresh weight reduction was higher in *Tagetes minuta* methanol extract at 30 and 25 per cent (5.13 and 5.37 g/plant, respectively) concentration sprayed on the day of sowing and followed by 30 and 25 per cent cold water extract of *Tagetes minuta* all spayed on the same day of sowing. Higher dry weight of 10.65 g/plant was observed from the control treatment applied only with water.

In rice, among the treatments applied on the day of sowing lower fresh weight was recorded from 30 and 25 per cent methanol extract of *Tagetes minuta* and was on par with all treatments except 25 and 30 per cent of *Andrographis paniculata* cold water extract and 30 and 25 per cent of hot water extract of *Tagetes minuta*. Rice dry weight in control without any treatment was 6.22 g/plant.

Table 41. Interaction between time of application and allelopathic extracts on fresh weight of cowpea, green gram and rice at month after sowing

Fresh weight (g/plant)						
Allelopathic extracts	**Time of application**					
	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing
	Cowpea		**Green gram**		**Rice**	
Cold water extract of *A. paniculata* @ 25 %	28.22	27.83	24.37	22.55	12.48	13.04
Cold water extract of *A. paniculata* @ 30 %	27.78	23.69	23.98	18.41	12.26	12.57
Methanol extract of *A. paniculata* @ 25 %	27.69	22.77	23.32	17.49	12.23	13.24
Methanol extract of *A. paniculata* @ 30 %	27.14	27.09	22.94	21.81	11.39	10.53
Cold water extract of *T. minuta* @ 25 %	25.28	22.30	21.08	17.02	9.98	11.19
Cold water extract of *T. minuta* @ 30 %	25.04	29.05	20.53	25.92	9.71	10.52
Hot water extract of *T. minuta* @ 25 %	29.65	26.18	26.46	22.25	13.20	12.08
Hot water extract of *T. minuta* @ 30 %	29.26	26.47	25.03	24.82	12.67	10.69
Methanol extract of *T. minuta* @ 25 %	24.53	27.32	20.26	24.09	9.37	11.09
Methanol extract of *T. minuta* @ 30 %	22.38	28.04	18.10	23.93	8.52	12.37
Control (distilled water)	29.47		25.28		13.09	
CD (0.05)	2.03					

Table 42. Interaction between time of application and allelopathic extracts on dry weight of cowpea, green gram and rice at month after sowing

Dry weight (g/plant)						
Allelopathic extracts	**Time of application**					
	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing	On the day of sowing	6th day of sowing
	Cowpea		**Green gram**		**Rice**	
Cold water extract of *A. paniculata* @ 25 %	10.77	10.96	9.74	7.92	5.61	4.92
Cold water extract of *A. paniculata* @ 30 %	10.33	12.24	9.35	3.78	5.39	5.78
Methanol extract of *A. paniculata* @ 25 %	10.24	11.32	8.69	2.86	4.86	4.37
Methanol extract of *A. paniculata* @ 30 %	9.69	11.64	8.31	7.18	4.52	3.66
Cold water extract of *T. minuta* @ 25 %	7.83	11.85	6.47	2.39	4.35	5.02
Cold water extract of *T. minuta* @ 30 %	7.59	11.60	6.45	11.29	4.11	4.65
Hot water extract of *T. minuta* @ 25 %	12.20	10.74	11.83	7.62	6.33	5.21
Hot water extract of *T. minuta* @ 30 %	11.81	11.02	10.40	10.19	5.80	5.82
Methanol extract of *T. minuta* @ 25 %	7.08	10.87	5.37	9.46	3.84	4.22
Methanol extract of *T. minuta* @ 30 %	5.93	10.89	5.13	9.30	3.50	5.50
Control (distilled water)	12.01		10.65		6.22	
CD (0.05)	1.27					

Discussion

5. DISCUSSION

The present study was undertaken with the objective of screening selected plants, *Tagetes minuta*, *Andrographis paniculata* and *Plectranthus ambonicus* for their allelopathic effect against weeds of field crops. The results obtained from the experiment, after further analysis is discussed in this chapter based on the literature available.

5.1. Experiment 1. Screening of selected plants for allelopathic potential against weeds

Germination count of weeds at weekly intervals

Major weeds observed in the experiment were *Panicum sp.*, *Boerhavia diffusa*, *Alternanthera philoxeroides*, *Emilia sonchifolia*, *Cleome viscosa*, and *Euphobia hirta*. Selected plants showed phytotoxic influence on weed flora.

Among the plants screened for their allelopathic potential, *Tagetes minuta* exhibited maximum allelopathic potential in delaying germination of weeds, followed by *Andrographis paniculata* and the least was by *Plectranthus ambonicus* (Table 8. and Fig. 1). Better allelopathic activity of *Tagetes minuta* and *Andrographis paniculata* could be correlated with their higher contents of total alkaloids (Table 4). As compared to *Plectranthus ambonicus* the mean total alkaloid content was higher in *Tagetes minuta* and *Andrographis paniculata* (0.485, 0.417 and 0.182 per cent respectively in *Tagetes minuta*, *Andrographis paniculata* and *Plectranthus ambonicus*). A significant negative correlation (0.89) was observed between mean total alkaloid content and germination count of weeds at first week.

Inhibitory effect of *Tagetes minuta* on sun spurge (*Euphorbia helioscopia*) and Johnson grass (*Sorghum halepense*) was reported by Sadia *et al*. (2015). According to them allelopathic effect of *Tagetes minuta* was due to the presence of secondary metabolites like alkaloids, tannins, saponins, flavonoids and terpenoids. Nagaraja and Deshmukh (2009) established the phytotoxic effect of *Andrographis paniculata* on the metabolic activities of *Parthenium hysterophorus*. They found that ground plant parts (leaves, stems, and roots) of *Andrographis paniculata* significantly inhibited the growth

parameters such as height, leaf production and number of seeds per plant of *Parthenium hysterophorus*.

Regarding method of extraction, maximum result was noticed for methanol extract and by cold water extraction (Table 8 and Fig. 2). Allelopathic efficacy of plants was found decreased when they were extracted by hot water. Better allelopathic performance of methanol extracts could be attributed to better extraction efficiency of secondary metabolites from plant samples. As compared to cold water and hot water extraction methods, the contents of alkaloids and flavonoids were higher in the methanol extracts (Table 4). Methanol extracts completely inhibited seed germination as compared with water extracts in *Triticum aestivum* and *Zea mays* (Waris *et al*., 2016).

With respect to concentration of extracts, the best results were obtained with higher concentrations of 30 and 25 per cent. The allelopathic effect was found decreasing with decrease in the concentration (Table 8 and Fig. 3). As per Azambuja *et al*. (2010) allelopathic potential of a plant was directly proportional to their concentration. Arora *et al.* (2015) also reported concentration dependent response of allelopathic plants. According to them, at lower quantities, germination was unaffected, but increased significantly when the concentration was increased.

In the 1st week, maximum delay in weed germination was observed in 30 per cent methanol extract of *Tagetes minuta* (6.67 nos./m^2), and the highest germination (168.33 nos./m^2) was in control treatment (Table 19 and Fig. 4). As compared to the control treatment 96.04 per cent suppression in germination count was observed at 1st week by the application of 30 per cent methanol extract of *Tagetes minuta*. It was on par with methanol extract of *Andrographis paniculata* at 30 per cent (8.33 nos./m^2) concentration. Methanol extract of *Andrographis paniculata* at 30 per cent concentration resulted in weed suppression of 95.05 per cent as compared to control. Various *Plectranthus ambonicus* extracts at different concentrations did not have any effect on the germination of weeds. As compared to *Plectranthus ambonicus* the per cent content of total alkaloids was higher in *Tagetes minuta* and *Andrographis paniculata* (0.851 and 0.562 per cent respectively) which might have contributed to their better allelopathic performance.

Allelopathic effect of plants was significant only for a short period of time *i.e.* up to one week after the application. During 2nd, 3rd and 4th weeks, weed germination counts were not significantly different. From the preliminary screening it could be observed that allelopathic plants *Tagetes minuta* and *Andrographis paniculata* could be effectively utilized for the pre emergence weed control. As per Xuan *et al*. (2005), effect of alleopathic plants in controlling or delaying of weed seed germination persisted in the soil for up to 10 days and then their magnitude of suppression of weeds would drastically reduce.

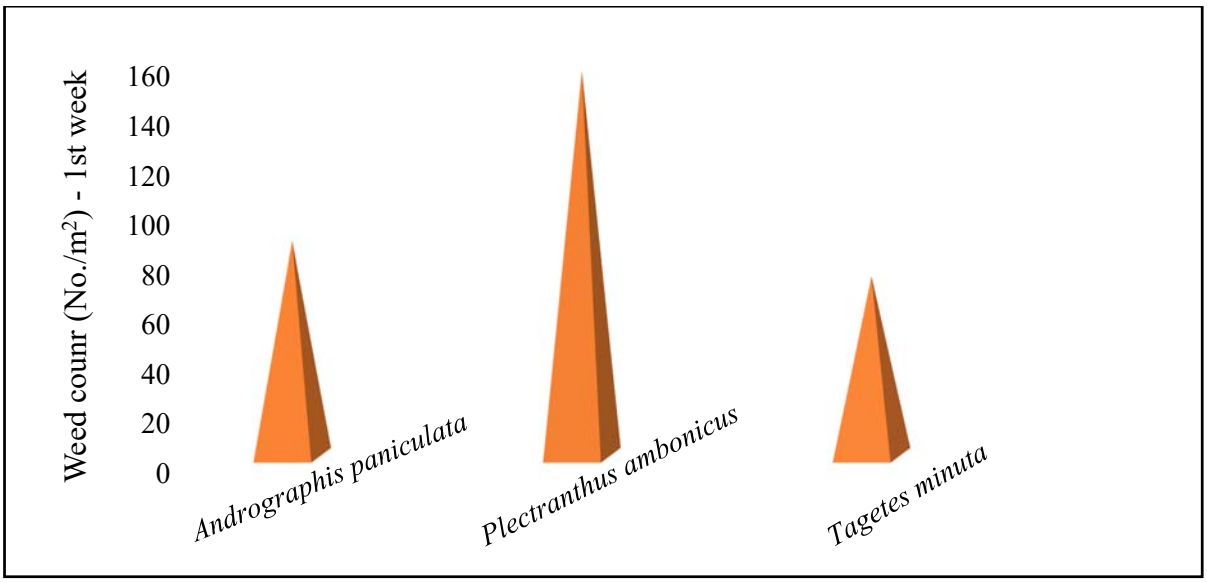


Fig. 1 Effect of allelopathic plants on weed germination at 1st week after application

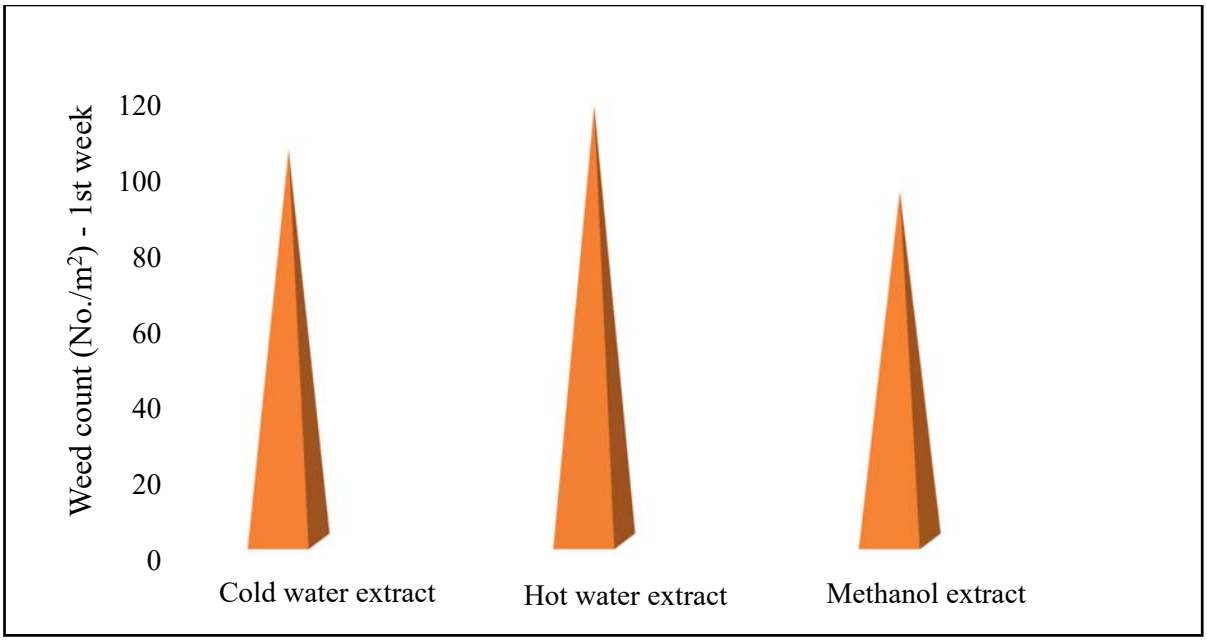


Fig. 2 Effect of methods of extraction on weed germination at 1st week after application

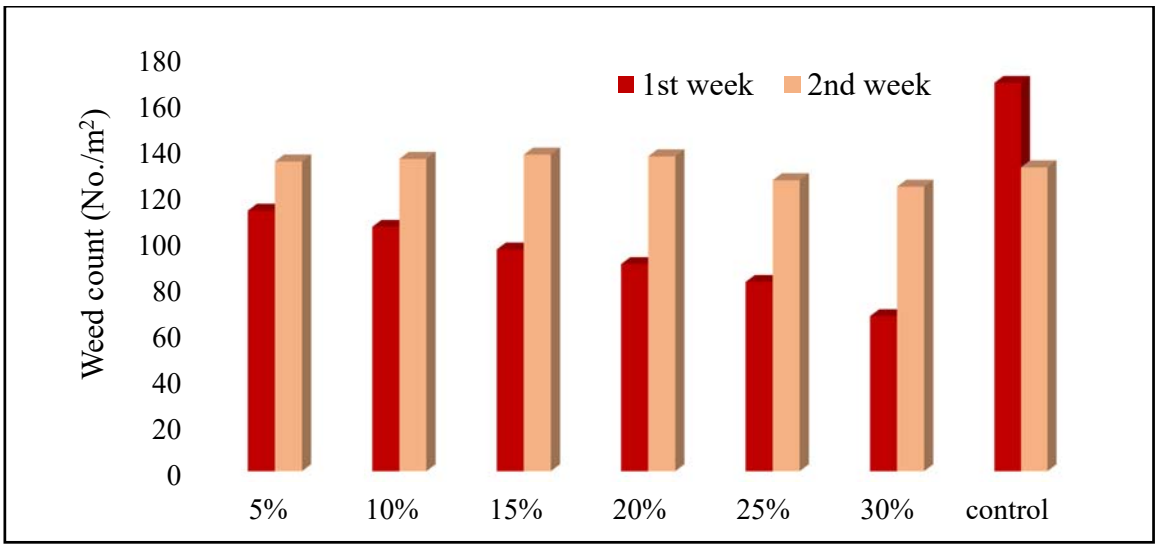


Fig. 3 Effect of concentrations on weed germination at 1st and 2nd week after application

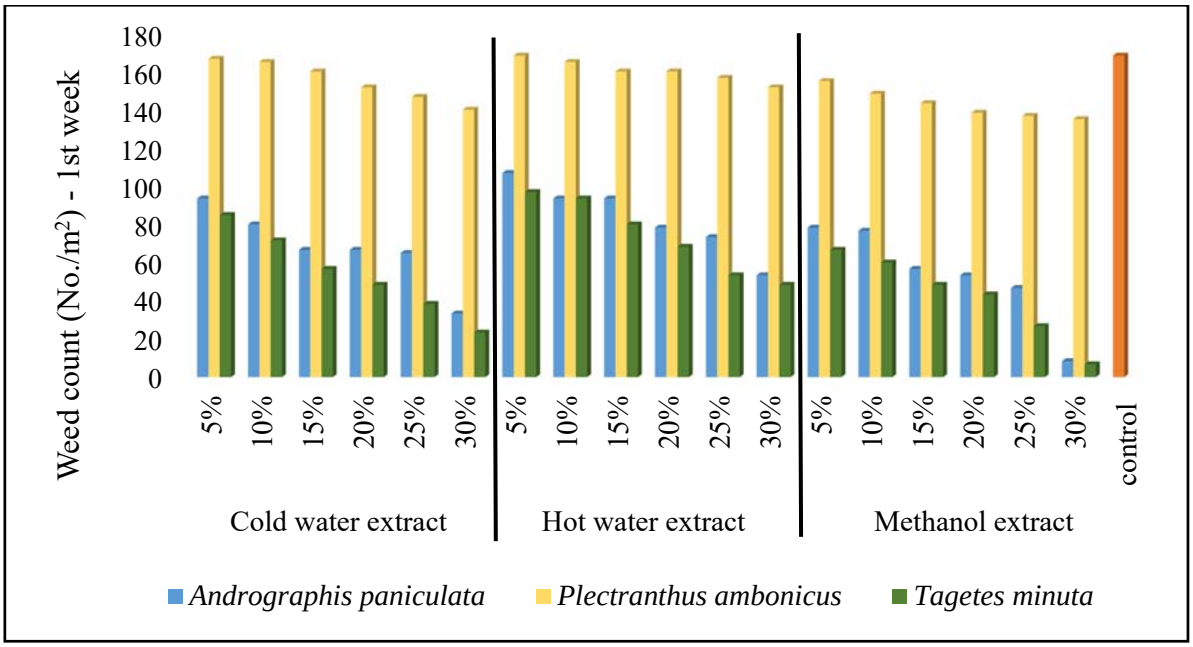


Fig. 4 Interaction effect of allelopathic plants, methods of extraction and concentrations at 1st week after application

Density and dry weight of weeds at one month after application

Weed densities (Tables 20a, 20b and 20c, Fig. 5 and 6) and dry weights (Tables 21a, 21b and 21c, Fig. 7 and 8) were recorded one month after application of treatments. The combined effect of allelopathic plants, methods of extraction and concentrations showed significant difference in weed density and dry weight of broad leaved weeds and total weeds at one month after application and but not on grass weeds. Aslani *et al*. (2014) reported that the dicot target plants were affected more severely than the monocots when treated with allelopathic plant extract.

Several reasons have been found for the different sensitivity of plant species to secondary metabolites in allelochemicals responsible as inhibitory compounds. It was due to the physiological and biochemical characteristics of each species (Kobayashi, 2004). Another study reported that difference responses to the same allelopathic extract on dicot and monocot was due to seed structure (Hodgson and Mackey, 1986) and seed coat penetrability (Hanley and Whiting, 2005).

Lower broad leaf weed density and total density were observed in methanol and cold water extracts of *Tagetes minuta* and *Andrographis paniculata* at 30 and 25 per cent concentrations (Plate 4). All the treatment combinations with these plants considerably reduced both density and dry weight of weeds as compared to control. However, all treatment combinations with *Plectranthus ambonicus* could not succeed in reducing either density or dry weight of weeds.

Several scientists reported allelopathic potential of *Tagetes minuta* (Kil *et al*., 2002; Batish *et al*., 2007; Arora *et al*., 2015). As per to reports, owing to the richness of allelochemicals, *Tagetes minuta* might play a very important role in weed management through allelopathic interactions. Similarly, Nagaraja and Deshmukh (2009), Li *et al*. (2010) and Kumar *et al*. (2018) reported inhibitory effect of *Andrographis paniculata* on dicot plants.

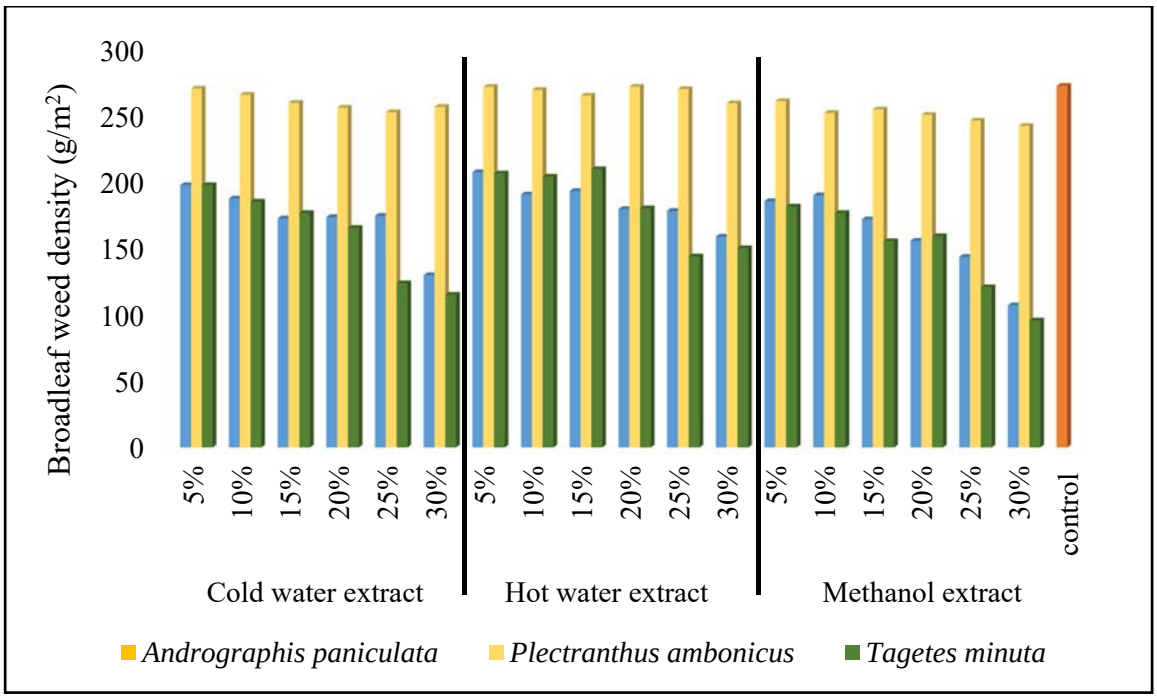


Fig. 5 Interaction effect of allelopathic plants, methods of extraction and concentrations on weed density of broad leaf weeds at one month after application

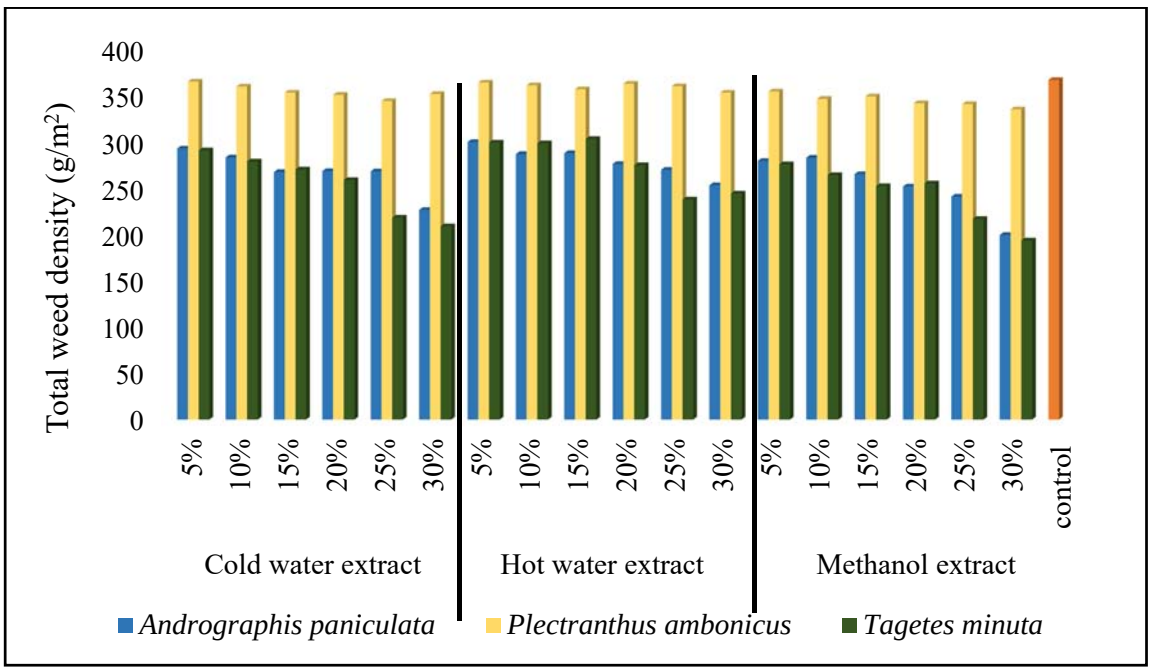


Fig. 6 Interaction effect of allelopathic plants, methods of extraction and concentrations on weed density of total weeds at one month after application

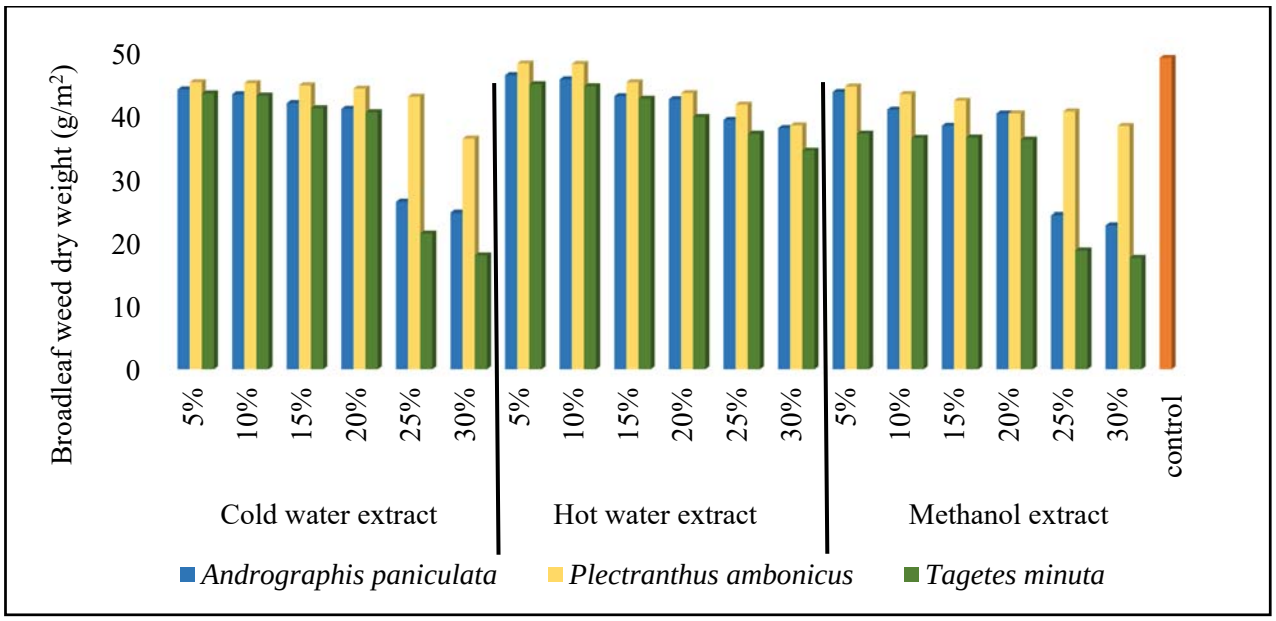


Fig. 7 Interaction effect of allelopathic plants, methods of extraction and concentrations on broadleaf weed dry weight at one month after application

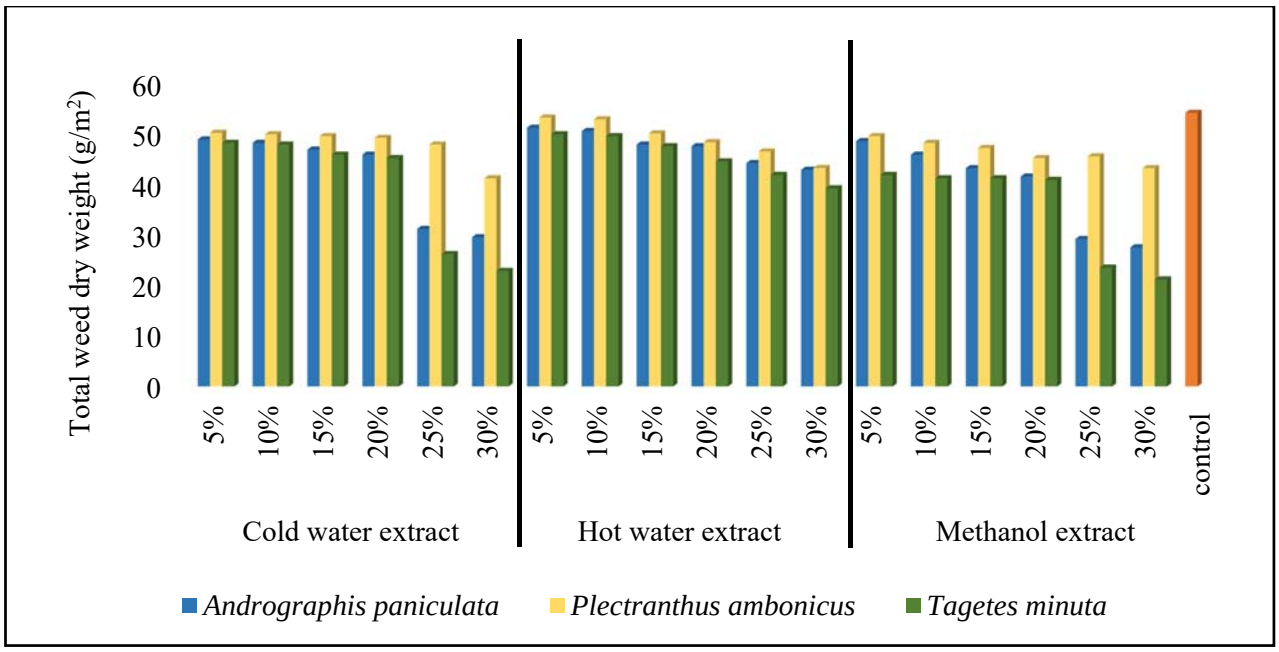


Fig. 8 Interaction effect of allelopathic plants, methods of extraction and concentrations on total weed dry weight at one month after application

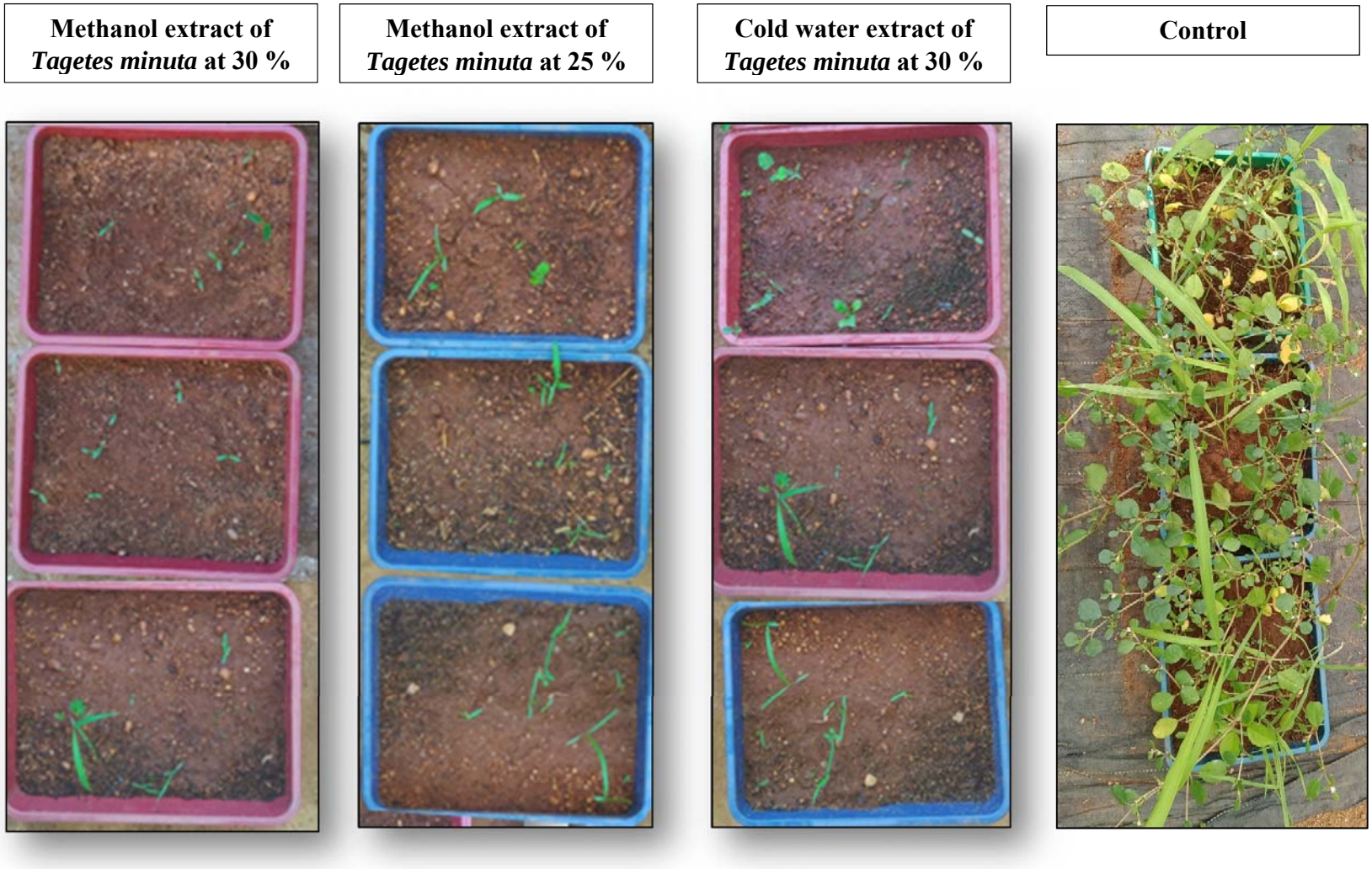


Plate 4. Weed germination count in best treatment and in control

5.2. Experiment 2 A and 2 B. Lab and pot culture studies on allelopathic effect of plant extracts on weeds and test crops

Germination and growth parameters of the test crops and weeds were significantly influenced by allelopathic extracts and their time of application. In this study, parameters like germination count, speed of germination, shoot and root lengths, fresh weight and dry weight of test crops and weeds were studied. All these parameters were reduced significantly when extracts were applied as pre emergence treatment.

5.2.1. A) Observations on test crops (cowpea, green gram and rice)

All the three test crops studied showed sensitivity to selected plant extracts. However, cowpea and green gram were more sensitive than rice. As compared to the control, application of methanol extracts of *Tagetes minuta* and *Andrographis paniculata* at 30 and 25 per cent concentrations on the day of sowing resulted in higher inhibition in all the parameters studied both in petri plate and in pot culture.

Days to germination of test crops

Cowpea placed in petri plates germinated on the 2nd day of sowing and that in pot culture germinated on 3rd day of sowing when applied with water as control (Fig. 9). Among the treatments, cowpea applied with 30 and 25 per cent of methanol and cold water extracts of *Tagetes minuta* and *Andrographis paniculata* started germinating on 4th day of sowing and only single seed germinated on 4th day. It took 12 days to complete germination in treatments with 30 and 25 per cent methanol extracts and 30 per cent cold water extract of *Tagetes minuta* whereas days taken for complete germination in control treatment was only three. Regarding green gram, maximum delay in germination was observed in 30 per cent methanol extract of *Tagetes minuta*, which took 5 and 11 days to start and complete germination as compared to single and three days in control. Delay in germination of dicot crops due to inhibitory effect of methanol extract from *Tagetes minuta* was reported by Jasper (2011).

Germination of rice seeds started on 6th day after sowing and completed by 9th day in control. The seeds treated with extracts of allelopathic plants showed extended germination. It took 14 days to complete germination in treatments of methanol extract of *Andrographis paniculata* at 30 per cent, cold water extract of *Tagetes minuta* at 30 per cent, and methanol extract of *Tagetes minuta* at 25 and 30 per cent. According to Weir *et al*. (2004), allelochemicals affect the growth and development of neighboring plants in different ways including germination inhibition and growth. Mandal *et al*. (2016) reported allelopathic potential of *Andrographis paniculata* in wheat. According to them seed germination and seedling growth of wheat was reduced considerably by the application of aqueous leaf extracts of *Andrographis paniculata* and the effect increased with increase in concentration.

In pot culture also delay in germination of test crops was observed due to application of plant extracts. Germination of cowpea seeds were first observed on 8th day of sowing and there was 5 days delay as compared to control when cowpea seeds were treated with 30 and 25 per cent of methanol extract of *Tagetes minuta*, and out of 12 seeds dibbled only 7 and 9 seeds only were germinated in the respective treatments. In 30 per cent of cold water extract of *Tagetes minuta*, out of 12 seeds only 10 seeds germinated (Table 32). Same trend was followed in green gram applied with these extracts. Green gram seed germination was delayed by 5 days compared to control. The highest allelopathic effect was for 30 and 25 per cent methanol extracts of *Tagetes minuta.* As compared to cowpea and green gram, inhibition in seed germination was not pronounced in rice. Out of 12 seeds dibbled only 3 seeds did not germinate when applied with 30 per cent of methanol extract of *Tagetes minuta*. As per Randhawa *et al.* (2002) when susceptible plant seeds are subjected to various allelochemicals, the germination rate may be reduced depending on the concentration of the extract.

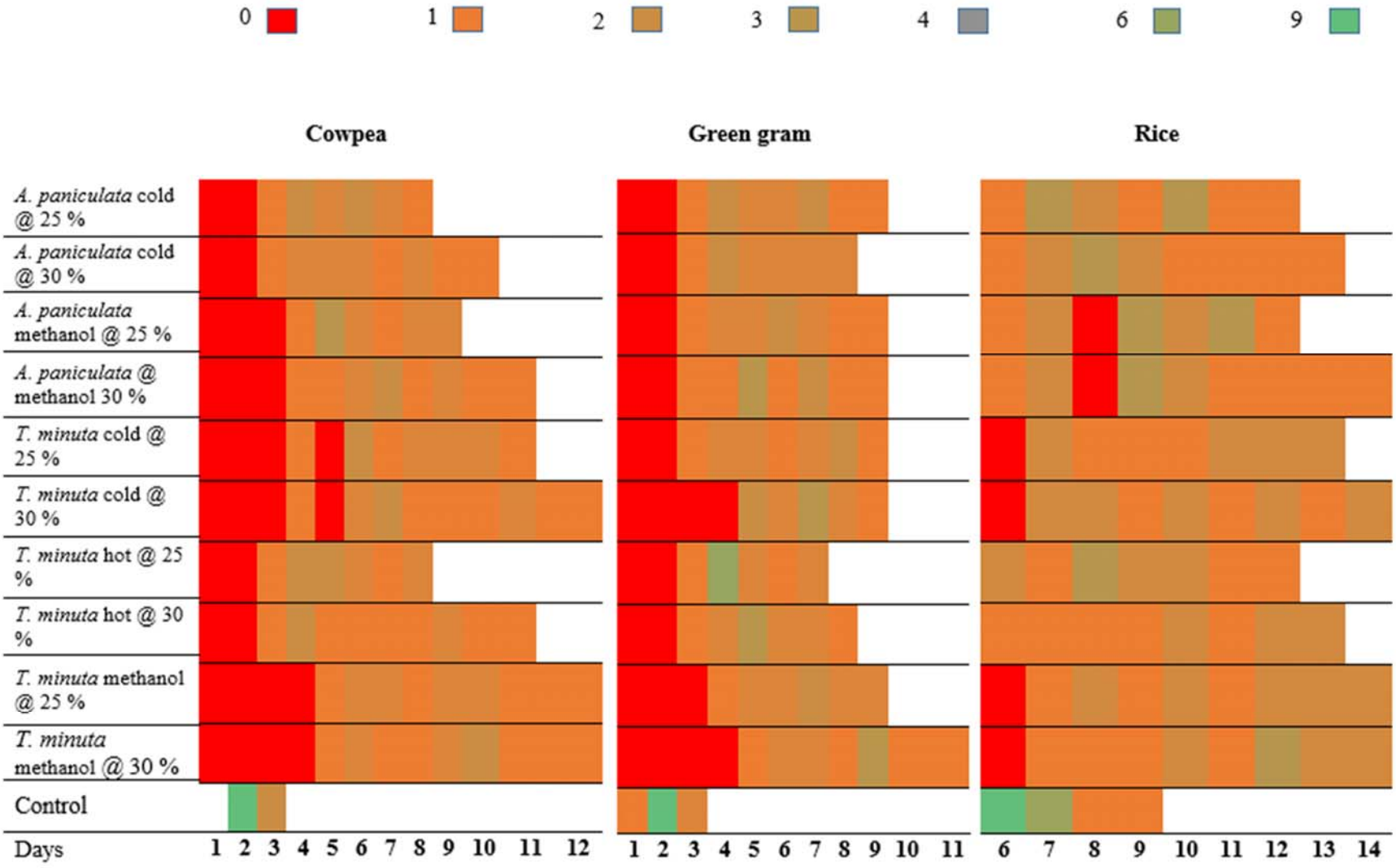


Fig. 9 Germination count in cowpea, green gram and rice by the application of allelopathic treatments

Speed of germination

The allelopathic treatments exhibited significant influence on speed of germination of cowpea, green gram and rice (Table 23, Fig. 10). All the treatments recorded lower speed of germination as compared to control. In cowpea, the lower speed of germination was noticed in 30 per cent *Tagetes minuta* methanol extract (1.55 no./day) and was on par with 25 per cent *Tagetes minuta* methanol extract (1.58 no./day), 30 and 25 per cent *Tagetes minuta* cold water extracts (1.62 no./day and 1.66 no./day). Maximum speed of germination was observed in control treatment (5.5 no./day).

Regarding green gram, the lowest speed of germination was in 30 per cent *Tagetes minuta* methanol extract (1.63 no./day) followed by 25 per cent *Tagetes minuta* methanol extract (1.89 nos./day). Control treatment recorded a speed of germination of 6.17 no./day. Rice seeds treated with 30 per cent *Tagetes minuta* methanol extract recorded the lowest germination speed (1.06 no./day) followed by 25 per cent methanol extract of *Tagetes minuta* (1.12 no./day). However, the reduction in speed was comparatively less than in the other two crops. Germination speed of rice was faster in control treatment (1.81 no./day). Reports state that the effect of allelochemicals on metabolic changes of receiver plants include effect on cell division, elongation, mineral uptake, enzyme activity and plant water relations and the effect was evident in terms of germination failure as well as delay in germination (Wink and Twardenski, 1992).

Shoot length of test crops

Plant extracts and their time of application had significant influence on the shoot length of test crops and effect was more pronounced in pre-emergence application and the effect lasted for one week. According to Iqbal *et al.* (2020), 40 per cent sorghum and brassica water extracts reduced dry biomass of *Trianthema portulacastrum* and *Cyperus rotundus* in cotton when applied pre-emergence.

Study conducted in petri plates (Tables 24a, 24b Fig. 11, Plates 5,6,7,8) showed that when extracts were applied as pre emergence (on the day of sowing) shoot length

reduction was maximum (26.17, 24.73 and 20.56 per cent) in cowpea, green gram and rice (Plates 5, 6, 7). However, at 15 days after sowing the reduction was only 3.71, 2.17 and 2.67 per cent. According to Xuan *et al*. (2005) persistence of allelochemicals and their activity on suppressing the growth of crops decreased with duration. According to allelopathic extracts (Fig. 12), maximum reduction noticed from petri plate study was with *Tagetes minuta* methanol extract at 30 per cent concentration for the three test crops. Compared with control, maximum shoot inhibition of 18.59,18.61 and 11.84 per cent was noticed from 7 days after sowing of cowpea, green gram and rice respectively and that from 15 days after sowing was only 4.46 and 2.12 per cent for cowpea and green gram respectively

Pot culture study conducted as part of this experiment also showed similar trend of maximum reduction in shoot length when extracts were applied pre-emergent (Table 33, Fig 13, Plate 9). The per cent reduction in shoot length at one month after germination when treatments were applied as pre emergence in pot culture study was 20.97, 26.35 and 7.7 in cowpea, green gram and rice respectively. Influence of extracts was more significant on cowpea and green gram as compared to rice. Li *et al*. (2021) also observed higher susceptibility of dicot plants to allelopathy than that of monocot plants. In the case of effect of allelopathic extracts (Fig. 14, maximum of 25.19 and 28.26 per cent shoot length reduction was recorded for *Tagetes minuta* methanol extract at 30 per cent concentration as compared to control treatment from cowpea and green gam respectively

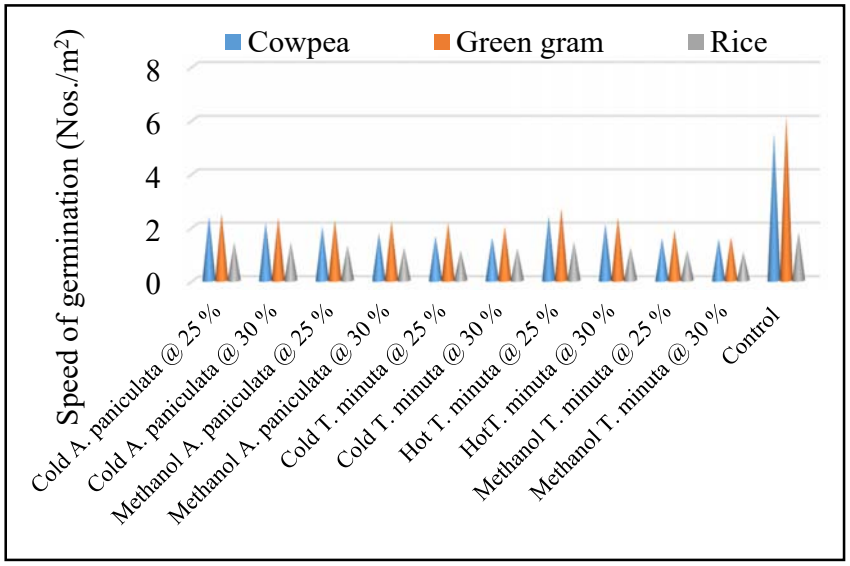


Fig. 10 Effect of allelopathic extracts on speed of germination of cowpea and green gram and rice (Petri plate study)

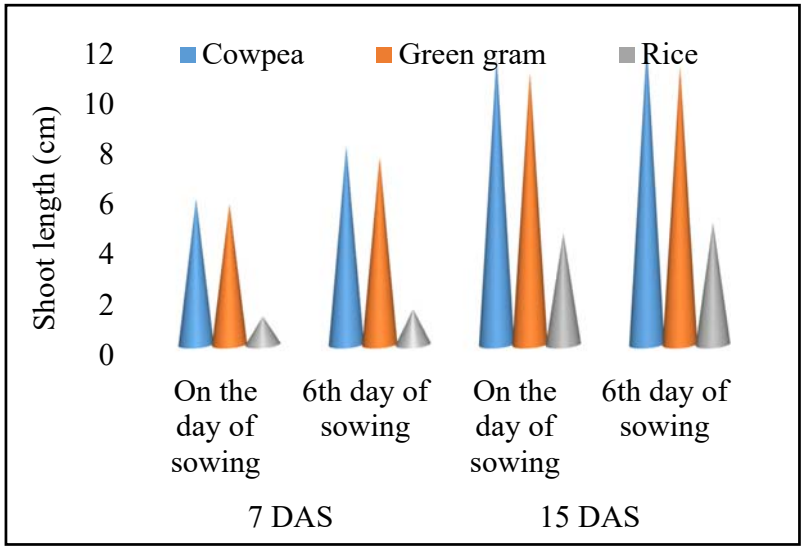


Fig. 11 Effect of time of application on shoot length of cowpea, green gram and rice at 7 and 15 DAS (Petri plate study)

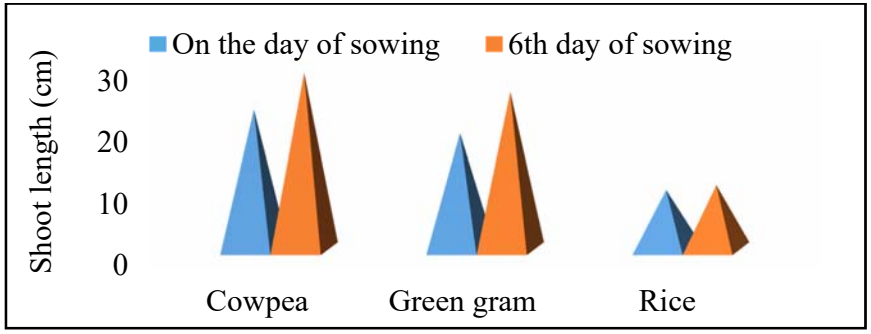


Fig. 12 Effect of time of application on shoot length of cowpea, green gram and rice at one month after application (Pot culture study)

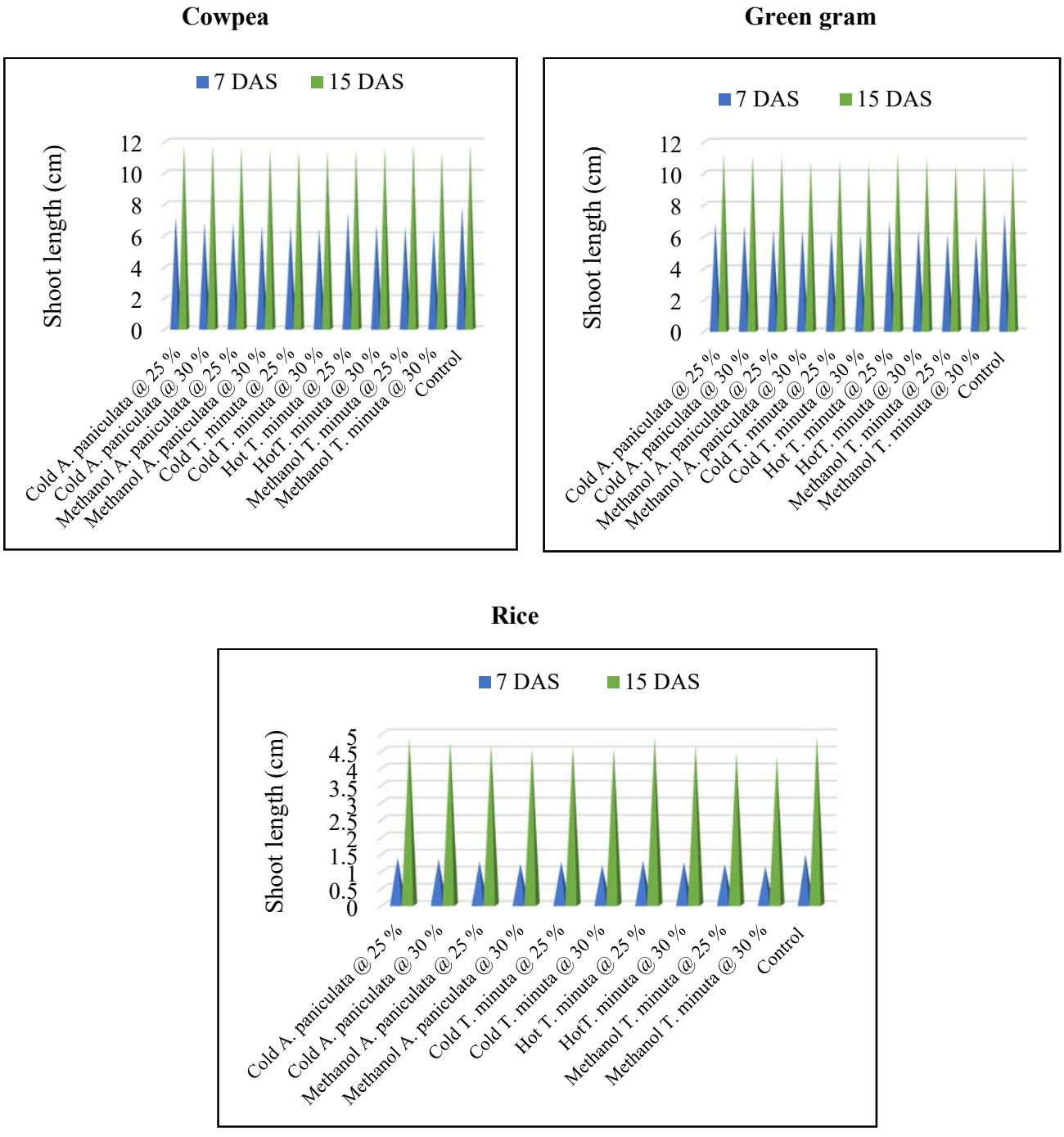


Fig. 13 Effect of allelopathic extracts on shoot length at 7 and 15 DAS

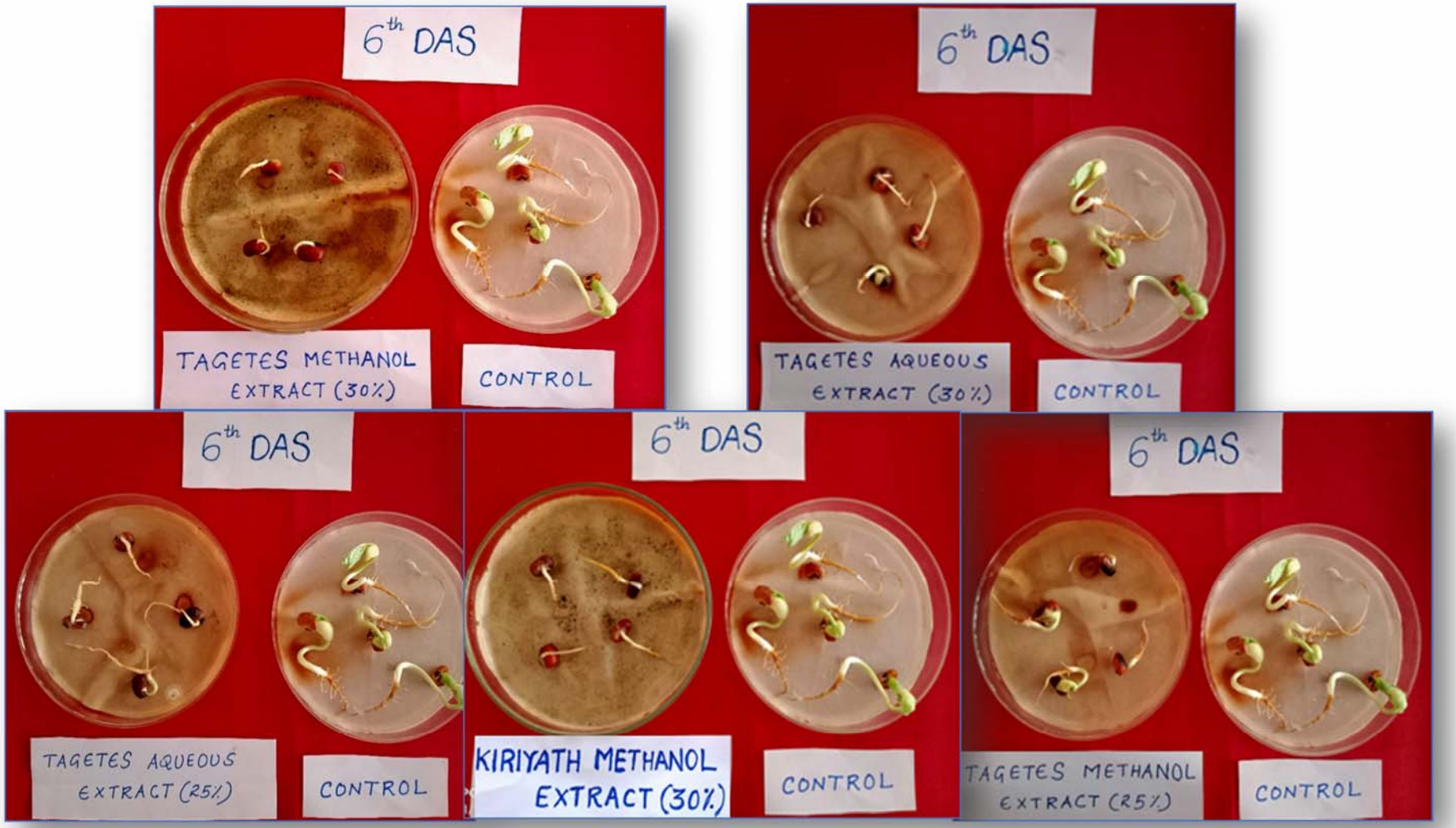


Plate. 5 Germination of cowpea at 1st week after treatment application

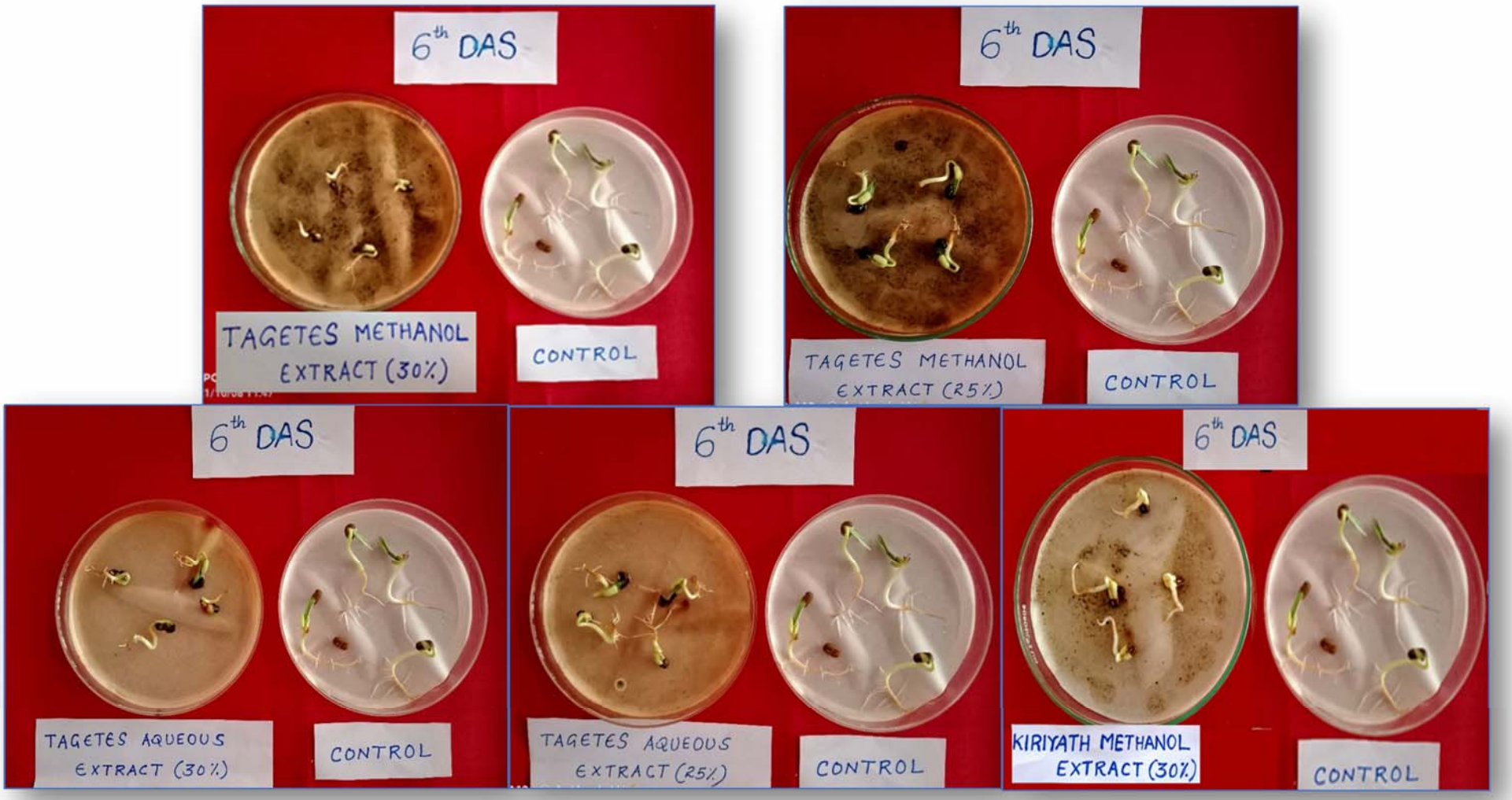


Plate. 6 Germination of green gram at 1st week after treatment application

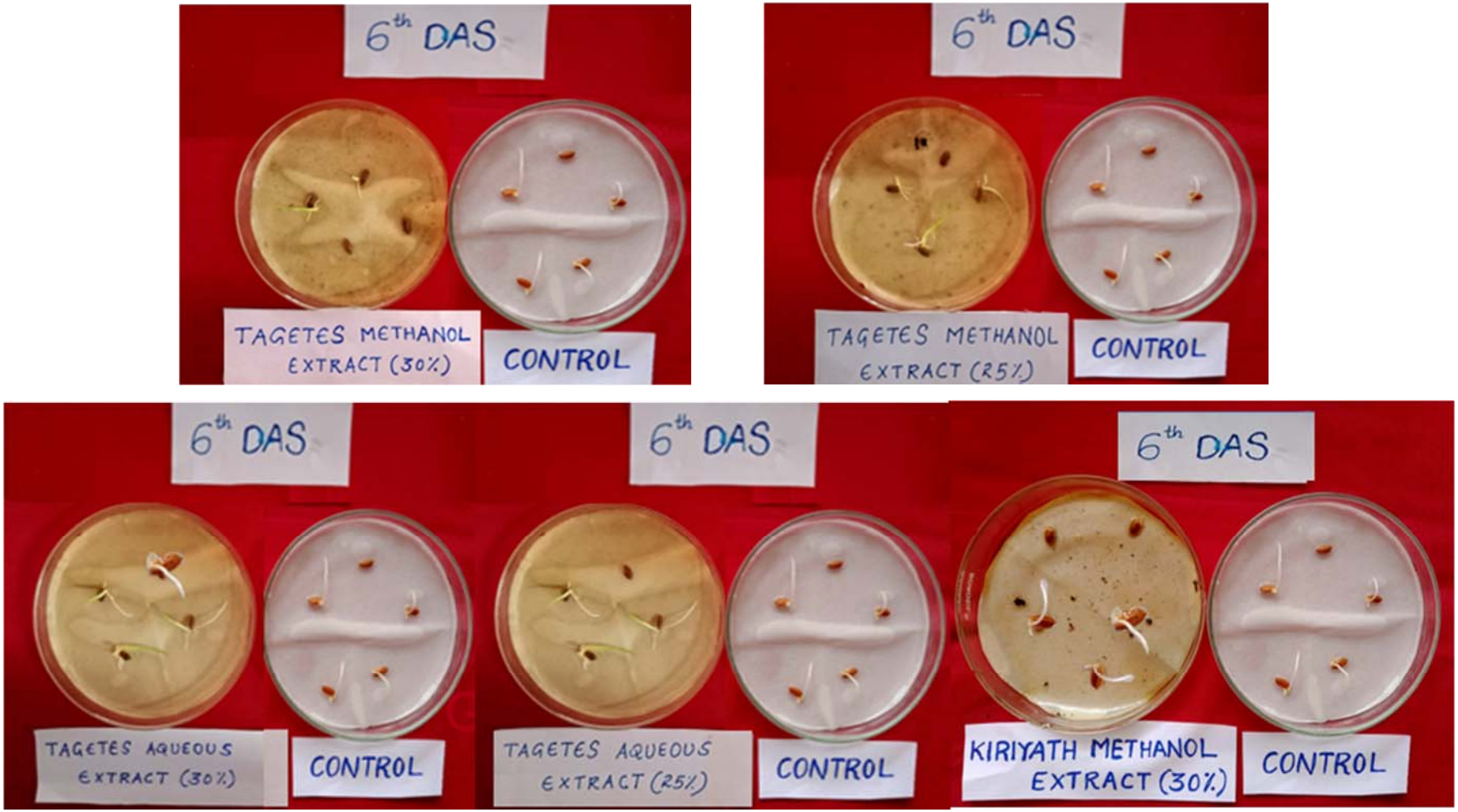
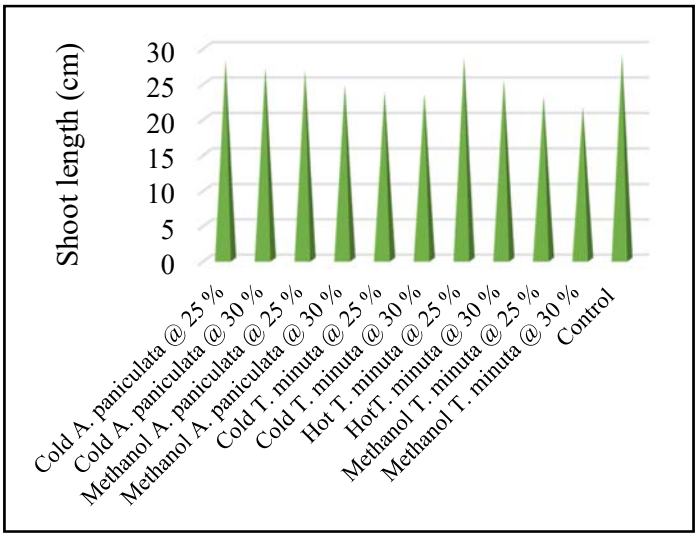


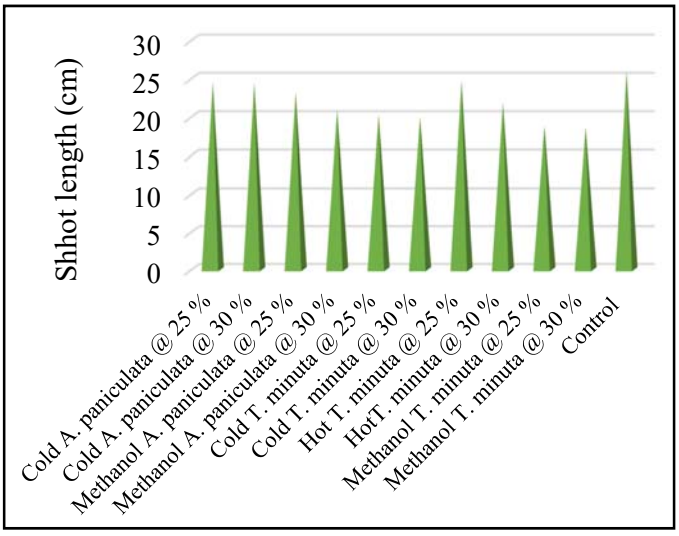
Plate. 7 Germination of rice at 1st week after treatment application

Plate. 8 Germination of cowpea, green gram and rice at 2nd week after treatment application

Cowpea



Green gram



Rice

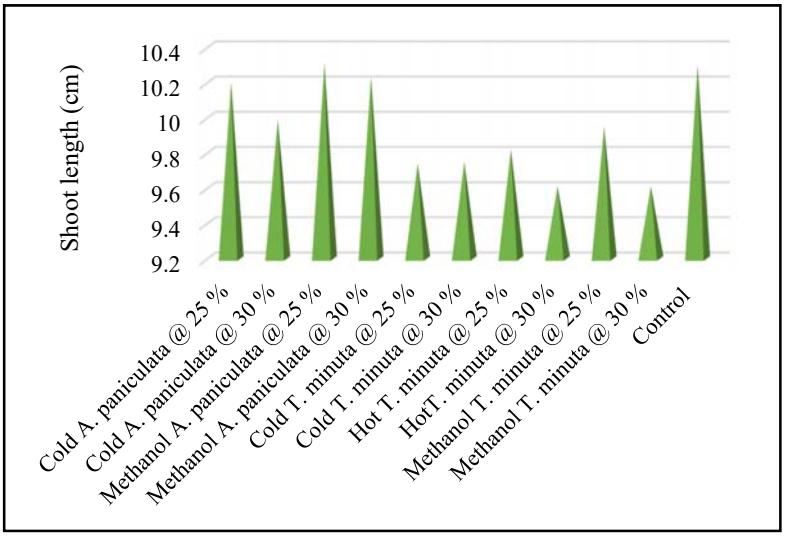


Fig. 14 Effect of allelopathic extracts on shoot length at one month after sowing

As per Rice (1984), reduced seed germination, coleoptile and radical elongation and root or shoot growth inhibition was the most common allelopathic symptoms. The observed reduction in seedling growth of test crops could be due to the presence of secondary metabolites such as alkaloids, tannins, flavonoids and phenols in allelopathic extracts. Allelochemicals influenced the cell division, cell elongation, enzyme activity and membrane permeability of test crops (Dragoeva *et al*., 2015).

For all the test crops higher reduction in shoot length was observed with 30 and 25 per cent methanol extract of *Tagetes minuta* and 30 per cent methanol extract of *Andrographis paniculata* applied on the day of sowing (Tables 27a, 27b, 27c, Fig. 15). In cowpea, at 7 days after sowing shoot length reduction of 37.32 and 36.43 per cent as compared to control was recorded in methanol extract of *Tagetes minuta* at 30 and 25 per cent respectively when applied on the day of sowing. With the same treatment combination shoot length reduction in green gram was 37.75 and 36.81 and in rice it was 41.49 and 37.41 per cent.

Similar results for shoot length reduction were observed in pot culture study also. In cowpea, higher shoot length reduction of 49.86 per cent as compared with control was recorded with *Tagetes minuta* methanol extract at 30 per cent followed by *Tagetes minuta* methanol extract at 25 per cent concentration (38.85 per cent) which was applied on the day of sowing. There was no effect when allelopathic extracts were applied 6 days after sowing and treatments were on par with control treatment. For green gram, shoot length reduction was 55.25 per cent and 53.01 per cent respectively with 30 and 25 per cent *Tagetes minuta* methanol extracts. Rice shoot length reduction was 13.68 per cent with 30 per cent *Tagetes minuta* methanol extract applied on the same day of sowing (Table 39, Fig. 16). Many researchers investigated the allelopathic potential of *Tagetes minuta* (Batish *et al*., 2007; Alhammadi, 2008; Arora *et al*., 2015) and reported its potential herbicidal action.

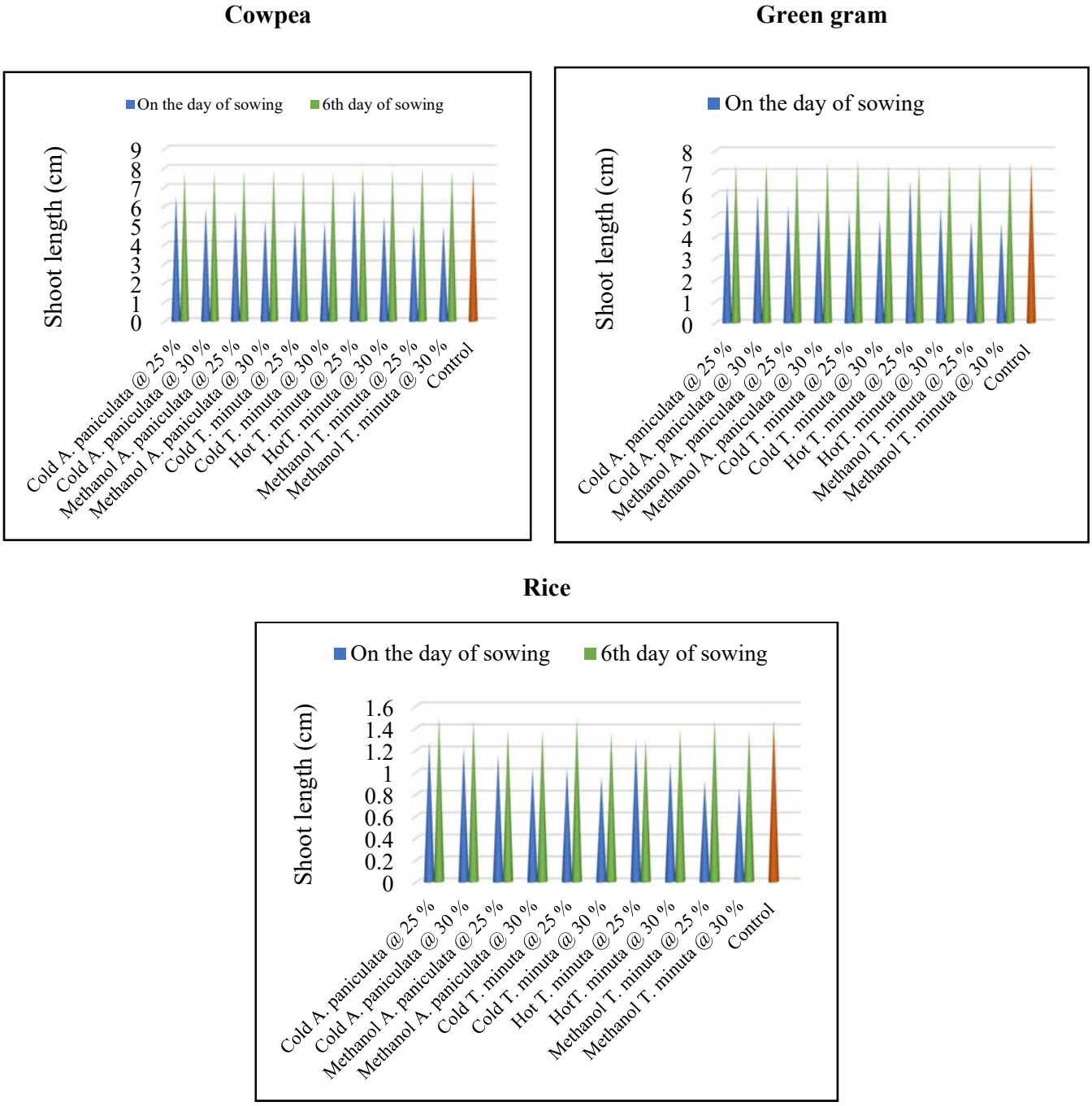


Fig. 15 Interaction between time of application and allelopathic extracts on shoot length at 7 DAS

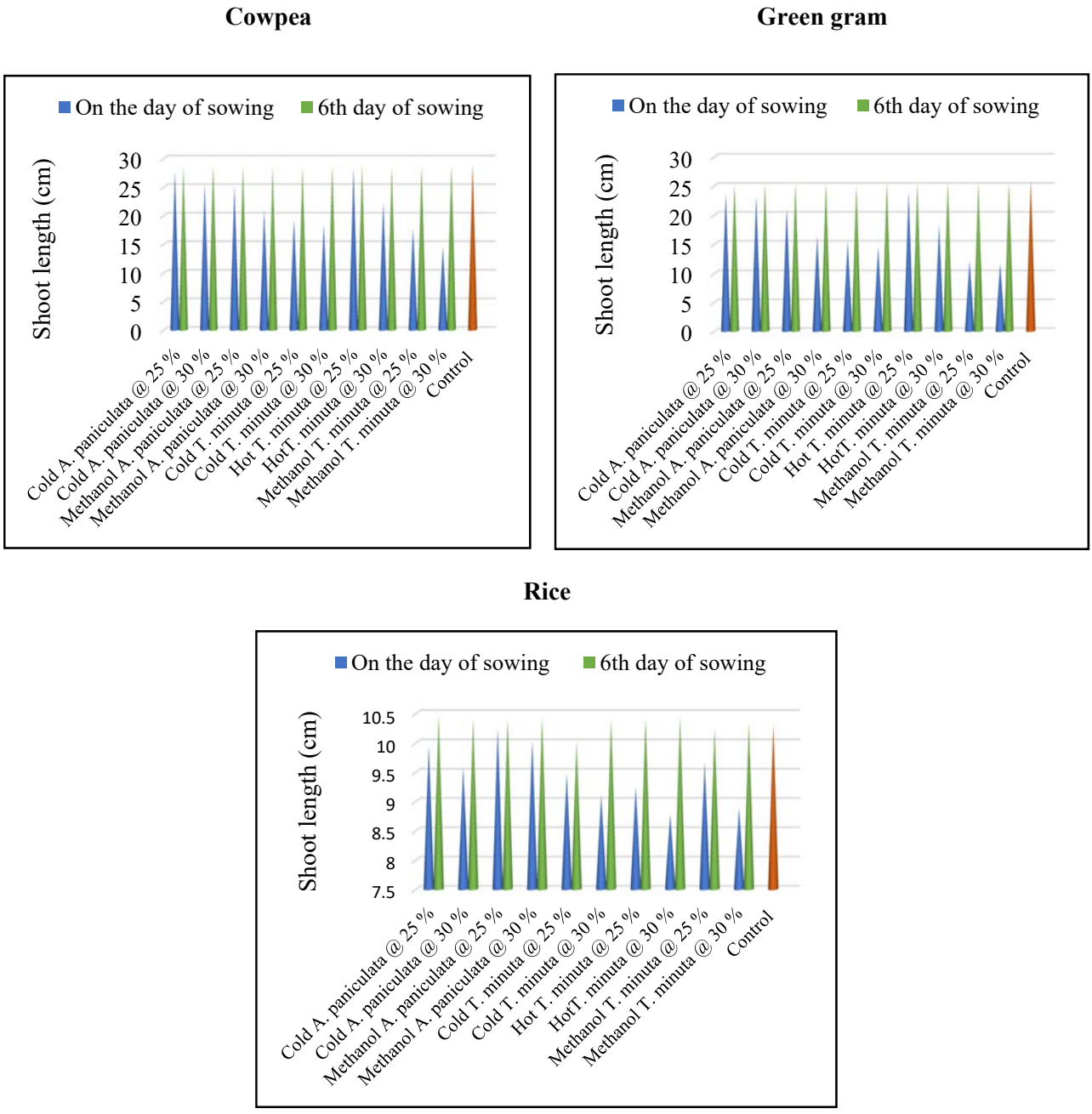


Fig. 16 Interaction between time of application and allelopathic extracts on shoot length of at one month after application

Plate. 9 Growth of cowpea, green gram and rice at one month after application of *T. minuta* extracts

Root length of test crops

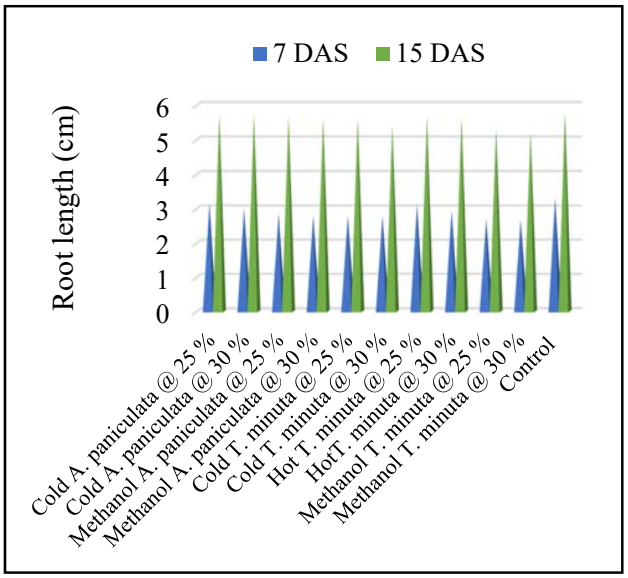
Influence of allelopathic extracts and their time of application was more conspicuous on root length than shoot length. Root length reduction was directly correlated with allelopathic plant, method of extraction and its concentration. Allelopathic extracts from sunflower, sorghum and rice reduced root and shoot lengths of *Parthenium hysterophorus* and the rate of reduction was more for roots than shoots (Javaid *et al*., 2006). The development rates of the roots and the shoot have been shown to be reduced by the allelochemicals. The roots of the test plants were more sensitive to the allelochemicals than the aerial parts of the seedling (Sajjad *et al*., 2007).

As in the case of shoot length, time of application significantly affected root length and the effect was more apparent when applied pre-emergence (Tables 25a, 25b, Fig. 17). Per cent suppression of root length at 7 DAS in cowpea, green gram and rice were 25.15, 26.91 and 10.48 when applied as pre emergence and effects lasted for one week. Same trend was observed for test crops dibbled in the pots also (Table 34, Fig, 18). Root inhibition of 43.21 and 32.40 per cent respectively for cowpea and green gram were observed at 7 DAS in pots applied with extracts on the day of sowing.

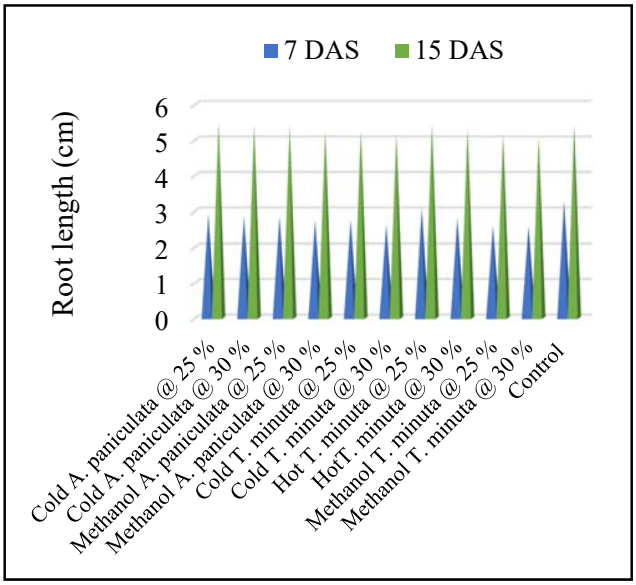
Treatments were more active on the dicots than the monocots (Fig. 19). Cowpea treated with *Tagetes minuta* methanol extract at 30 per cent recorded shoot length reduction of 19.58 per cent at 7 days after sowing and 9.50 per cent at 15 days after sowing, indicating short residual life of extracts. In the case of green gram, maximum shoot suppression was observed with 30 and 25 per cent *Tagetes minuta* methanol extract applied on the day of sowing and was 21.34 and 21.04 per cent at 7 days after sowing and decreased to 6.27 and 5.17 per cent on 15 days after sowing. In the case of rice, maximum root suppression was observed in treatment with 30 and 25 per cent *Tagetes minuta* methanol extract and it was 6.48 and 6.18 per cent at 15 days after sowing and not significant at 7 days after sowing.

Under pot culture also significant reduction in root length at one month after sowing was observed for cowpea, green gram and rice (Table 34, Fig. 20). In cowpea and green gram 35.38 and 36.07 per cent reduction in root length was recorded in *Tagetes minuta* methanol extract at 30 per cent concentration as compared to control. In rice it was 4.71 and 4.35 per cent with 30 and 25 per cent methanol extract of *Tagetes minuta*.

Cowpea



Green gram



Rice (15 DAS)

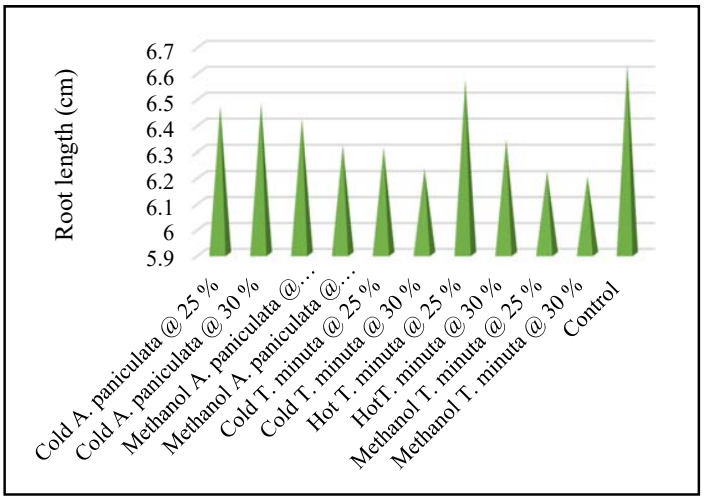
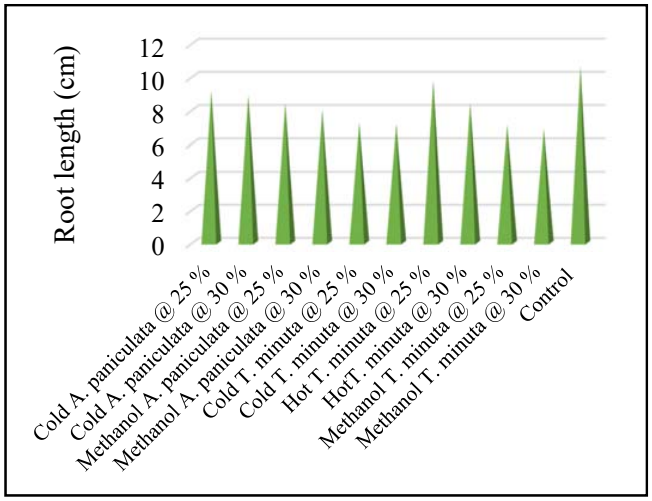
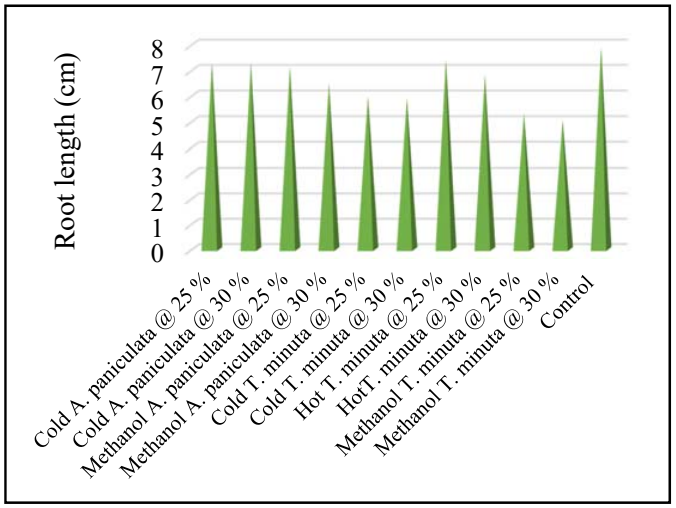


Fig. 17 Effect of allelopathic extracts on root length at 7 and 15 DAS

Cowpea



Green gram



Rice

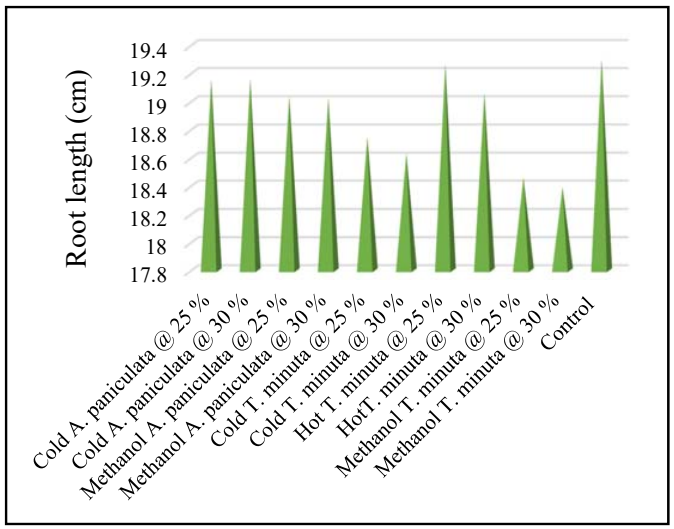
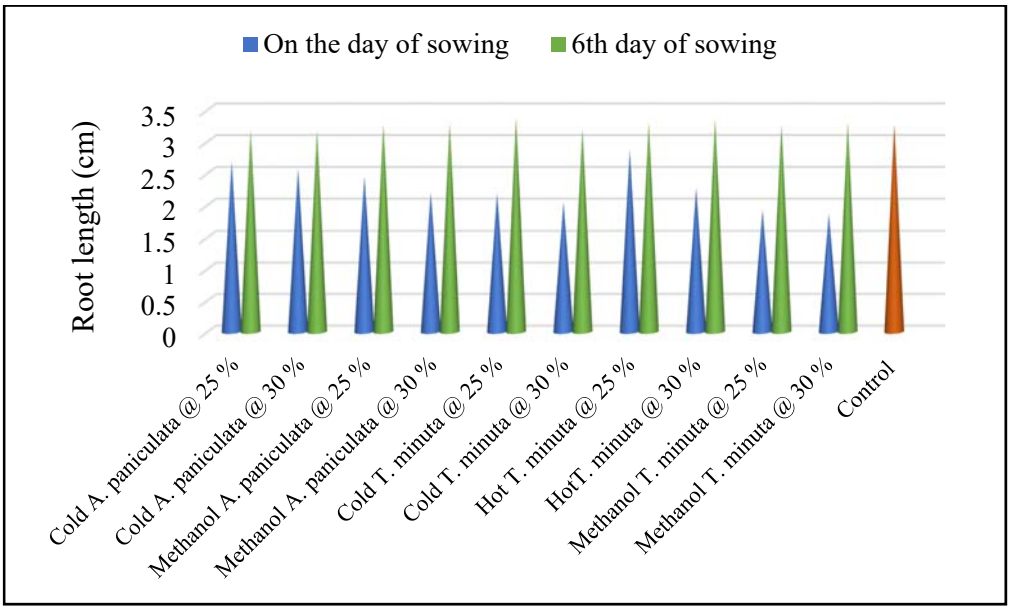


Fig. 18 Effect of allelopathic extracts on root length at one month after sowing

Cowpea



Green gram

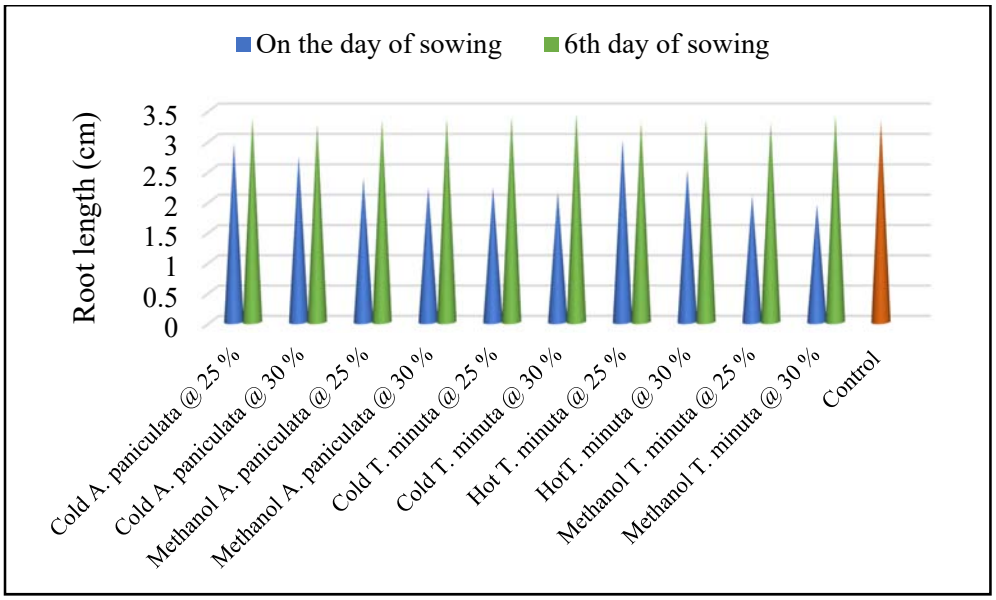
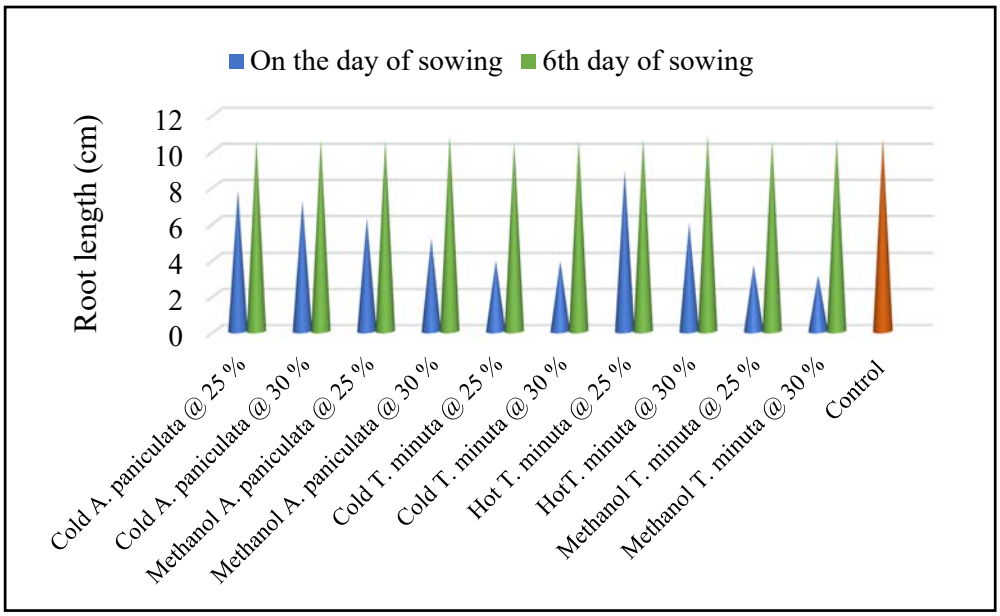


Fig. 19 Interaction between time of application and allelopathic extracts on root length at 7 DAS

Cowpea



Green gram

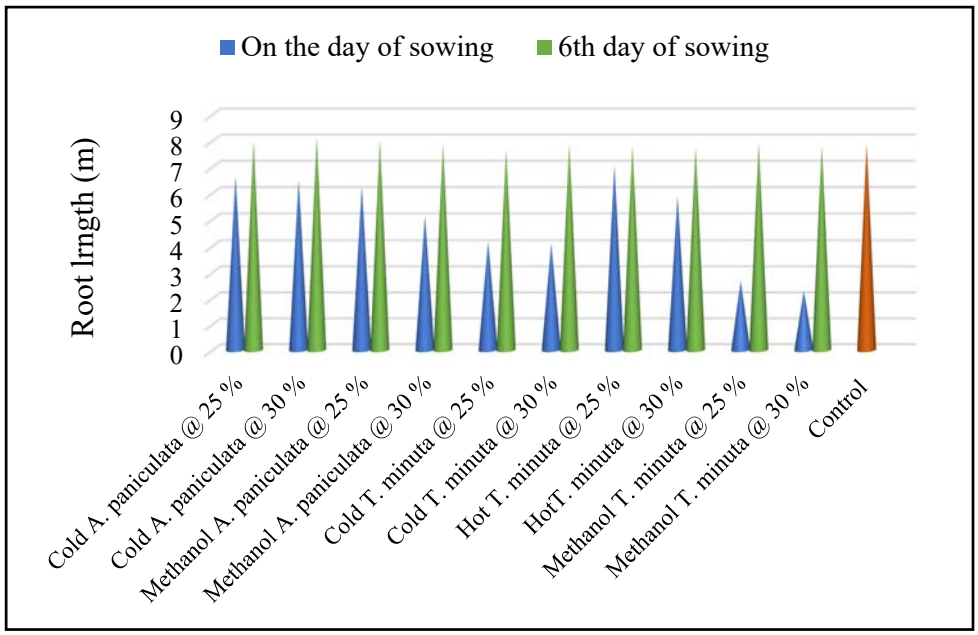


Fig. 20 Interaction between time of application and allelopathic extracts on root length at one month after application

On microscopic observation root decay in test crops were observed. Cowpea and green gram were more sensitive to pre emergence application of allelopathic plant extracts than rice and showed maximum decay. The decaying of roots started from the tip and progressed upwards (Plate 10). When extracts were applied pre-emergence, in pot culture study the number of rootlets of cowpea and green gram were less as compared to control (Plate 11 and 12). Kil *et al*. (2002) and Arif (2008) reported reduction in root growth and root decay in *Acacia asak*, *Lotus comiculatus* var. *japonicas* and *Lactuca sativa* by the application of aqueous extracts of *Tagetes minuta*. According to them aqueous extract of *Tagetes minuta* had more inhibitory activity on roots than shoots. Alhammadi (2008) also studied the allelopathic potential of *Tagetes minuta* leaf extracts and observed strong radicle growth inhibition and burning of the radicle tips.

Plate. 10 Root decay in cowpea and green gram

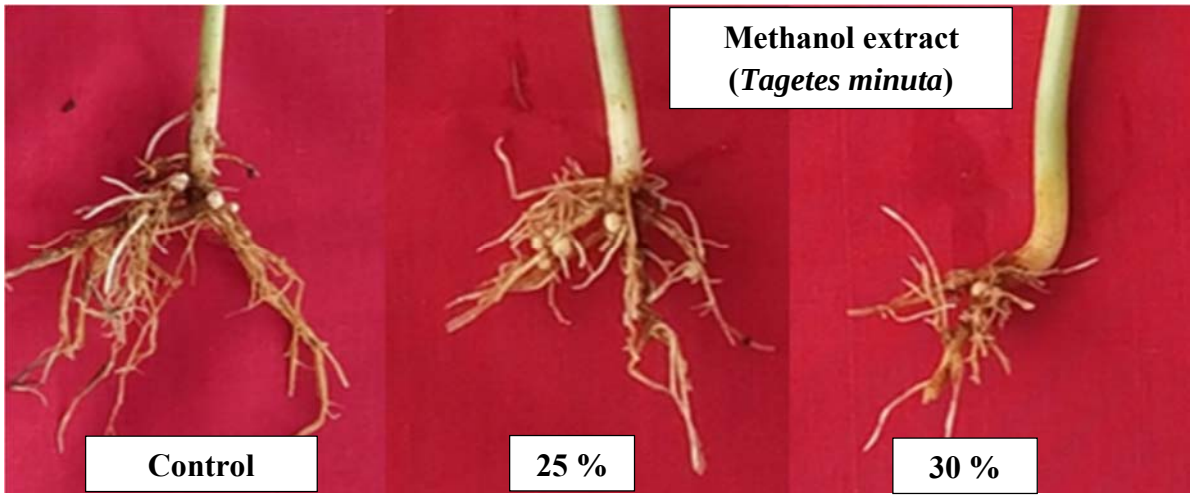


Plate. 11 Rootlets from cowpea

Plate. 12 Rootlets from green gram

Fresh weight and dry weights of test crops

Both fresh and dry weights of crops were significantly influenced by allelopathic extracts and application time. Weight reduction was more apparent in cowpea and green gram than rice (Tables 26a, 26b, Fig. 21). At 7 days after sowing fresh weight reduction of 60 per cent was noticed in cowpea and green gram applied with allelopathic extracts on the day of sowing. In pot culture study, fresh weight reduction was 30.26, 28.05 and 25.93 per cent respectively in cowpea, green gram and rice applied with extracts on the day of sowing (Table 35, Fig. 22). Highest fresh weight reduction of 96.00 per cent, 96.58 and 94.01 per cent were observed when cowpea, green gram and rice seeds respectively were treated with *Tagetes minuta* methanol extract at 30 per cent, compared to control (Fig. 23).

The effects of allelopathic plant extracts not only limited to the shoot and root inhibition, but also influenced the dry weight of test crops by reducing the length of shoot and root. As compared to post emergent application at 6 days after sowing, test crops showed significant reduction in dry weight when applied as pre-emergence in pot culture study (Table 36, Fig. 24). Highest dry weight reduction was recorded from methanol extract of *Tagetes minuta* at 30 per cent concentration sprayed on the day of sowing as compared to control. The reduction noticed in cowpea, green gram and rice was 87.87, 89.54 and 84.82 per cent respectively (Fig. 25). Less sensitivity of rice to allelopathic plant extracts could be utilized in field condition to control rice weeds. Batish *et al*. (2007) also suggested application of *Tagetes minuta* extracts for the control of rice weeds as rice was not affected by it.

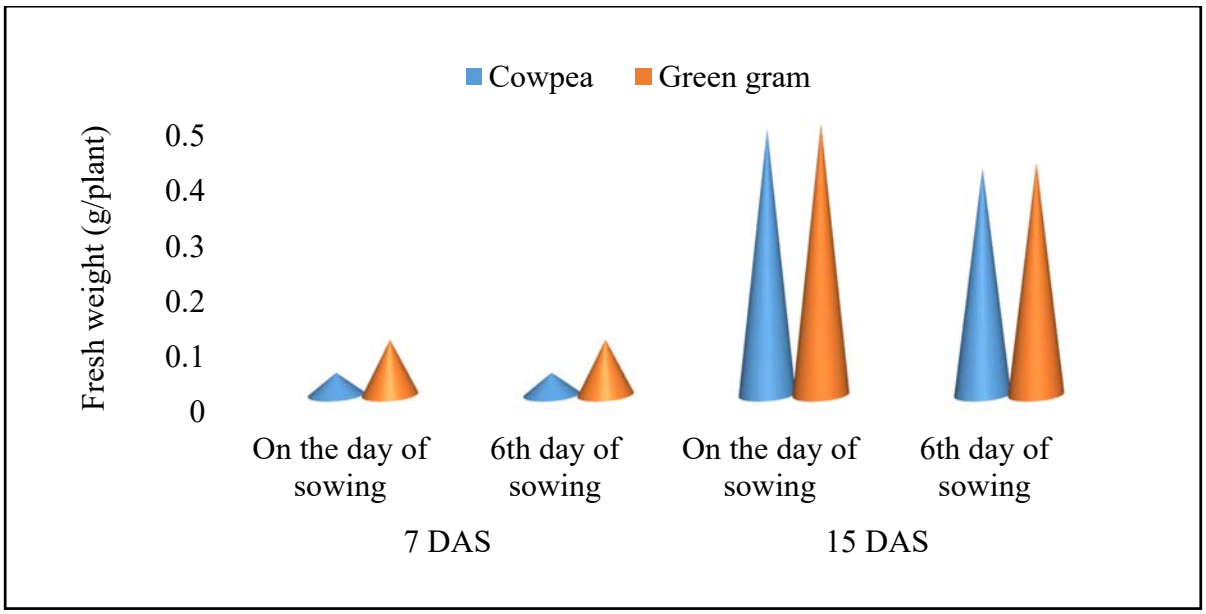


Fig. 21 Effect of time of application on fresh weight of cowpea and green gram at 7 and 15 DAS (Petri plate study)

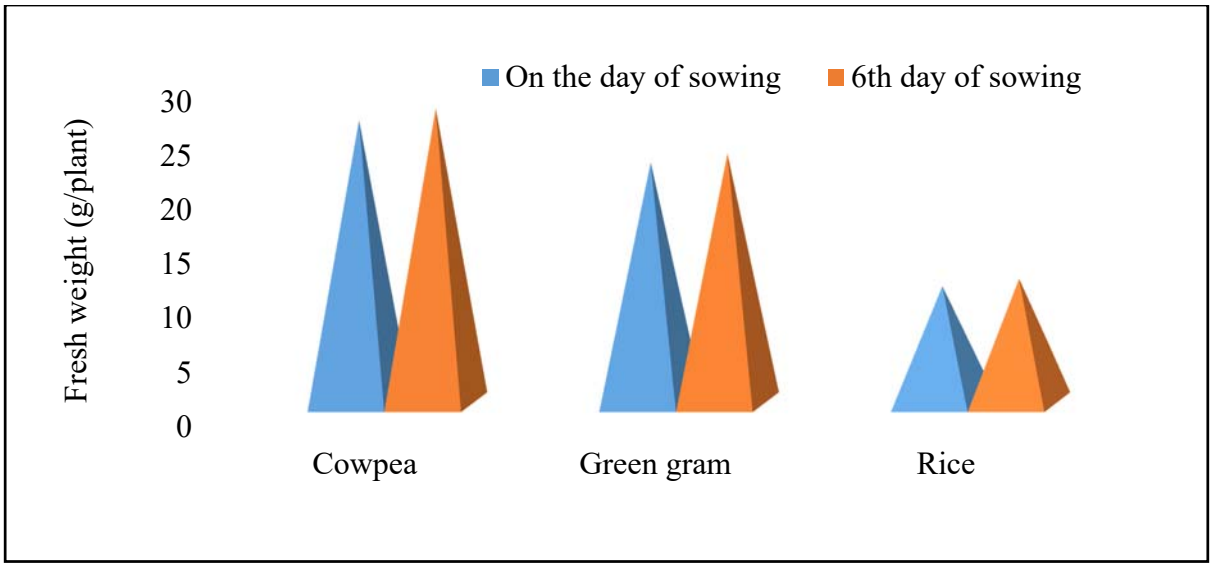
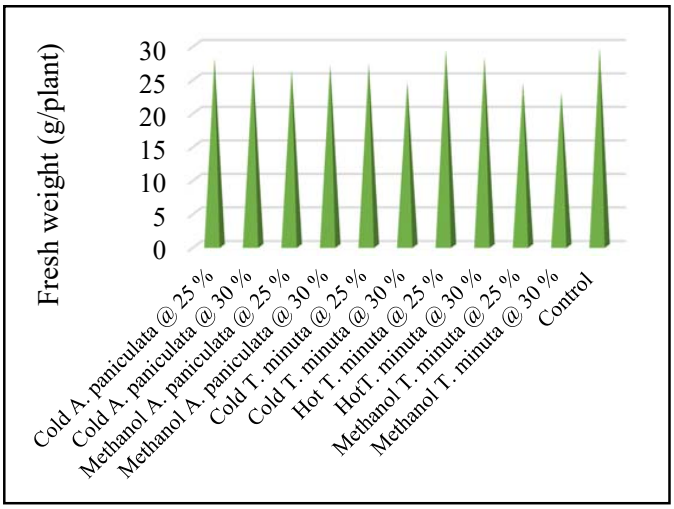
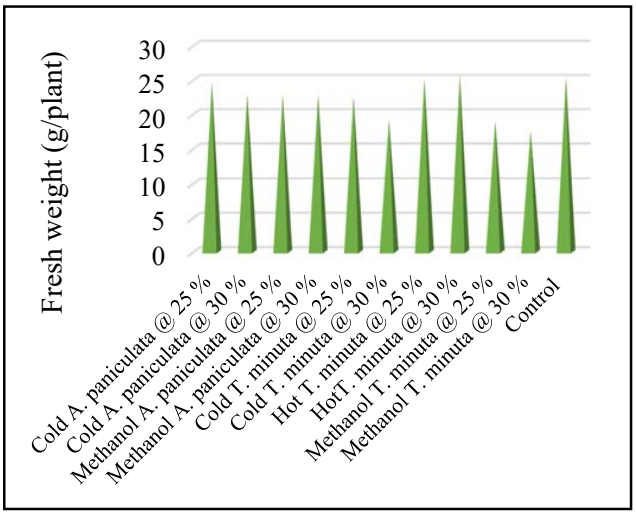


Fig. 22 Effect of time of application on fresh weight of cowpea and green gram and rice at one month after application (Pot culture study)

Cowpea



Green gram



Rice

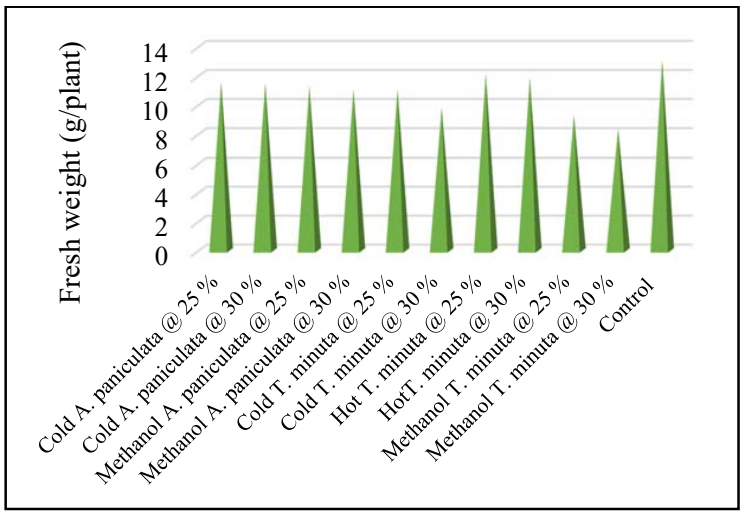
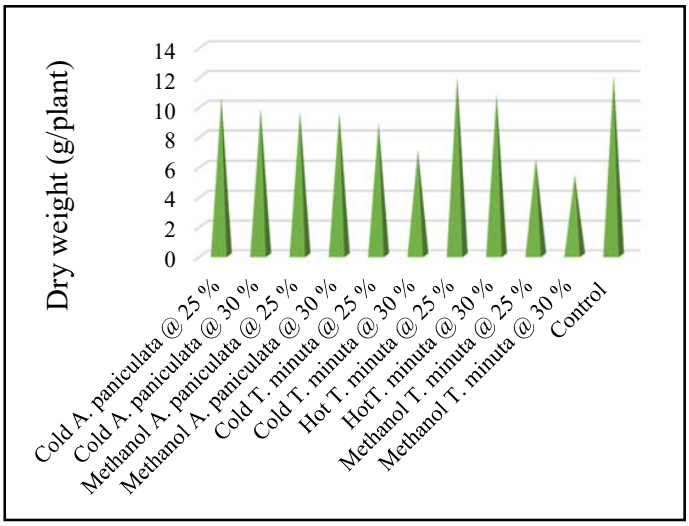
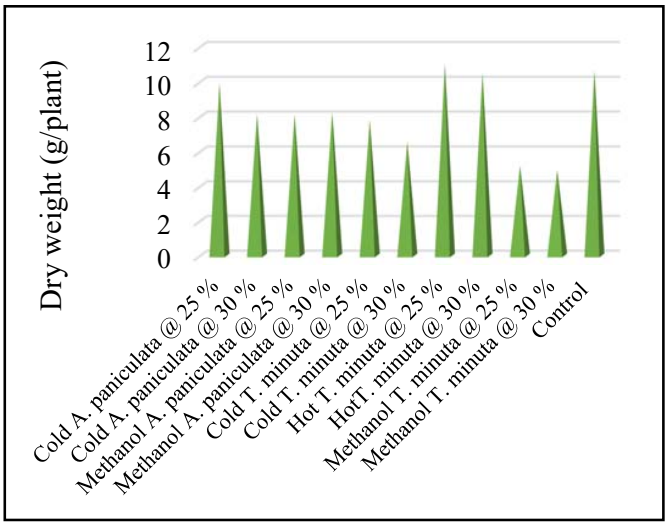


Fig. 23 Effect of allelopathic extracts on fresh weight of test crops at one month after sowing

Cowpea



Green gram



Rice

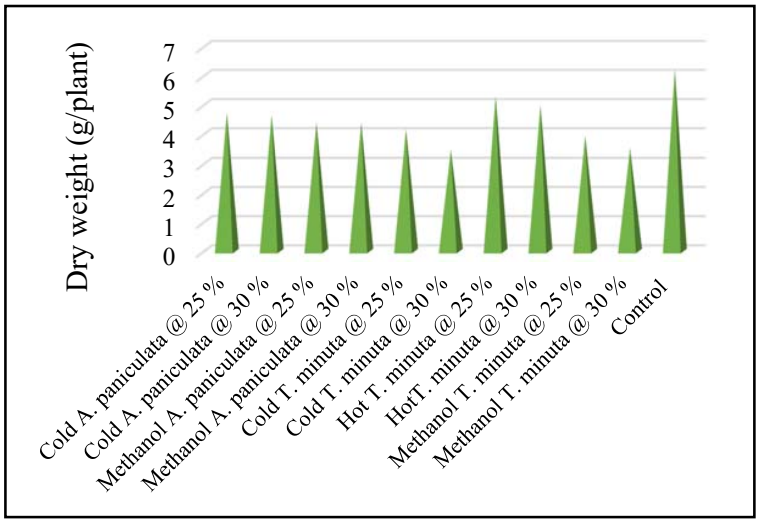
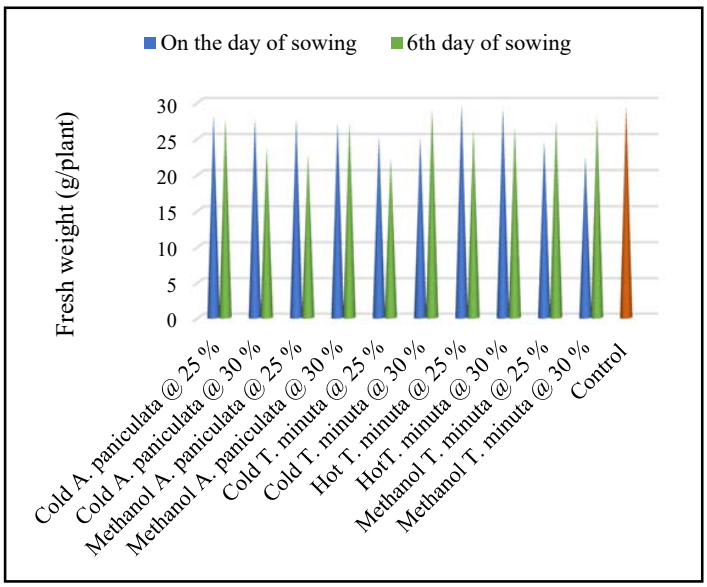


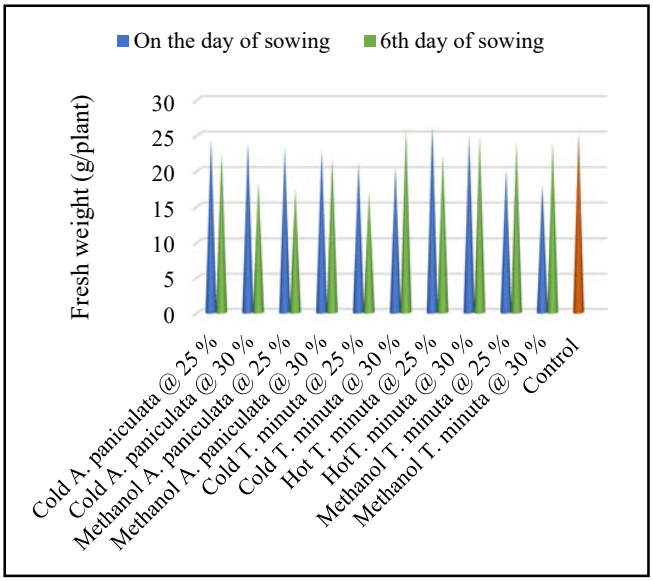
Fig. 24 Effect of allelopathic extracts on dry weight of test crops at one month after sowing

Interaction effect between time of application and allelopathic extracts showed significant difference in fresh and dry weight compared with control (Tables 41 and 42, Fig. 25, 26). The highest fresh weight and dry weight reduction per cent was recorded with methanol extract of *Tagetes minuta* at 30 per cent concentration sprayed on the day of sowing as compared to control, and reduction noticed from cowpea, green gram and rice was 76.17, 71.60 and 65.09 per cent fresh weight and 49.37, 48.17 and 56.27 per cent dry weight respectively.

Cowpea



Green gram



Rice

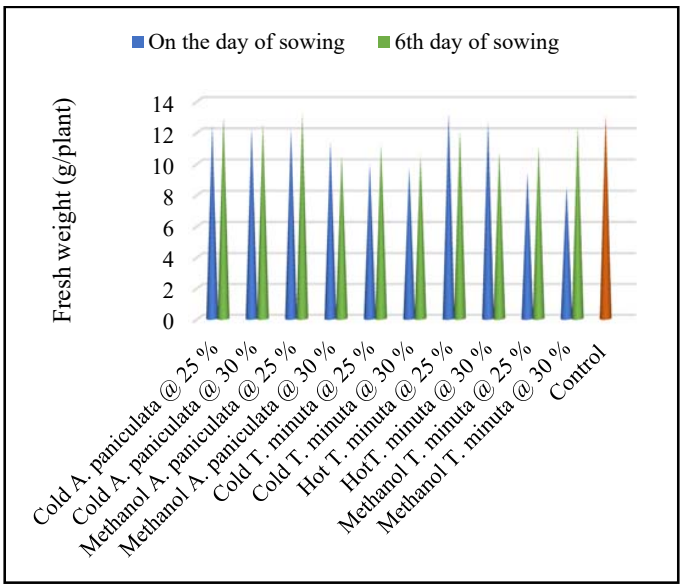
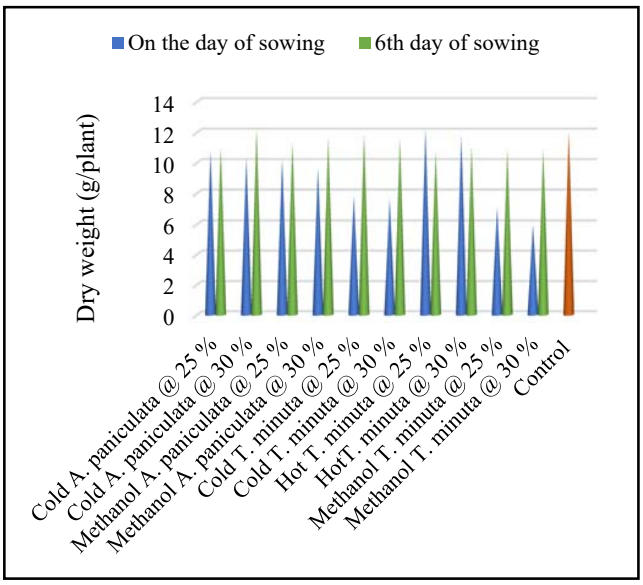
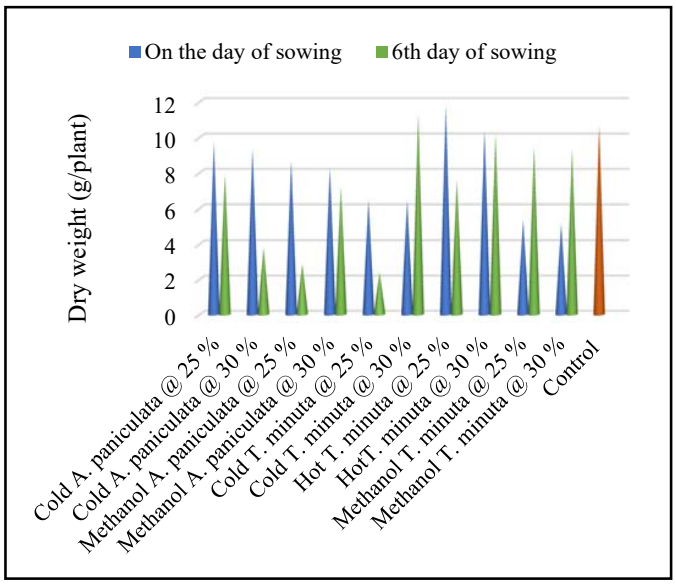


Fig. 25 Interaction between time of application and allelopathic extracts on fresh weight at one month after application

Cowpea



Green gram



Rice

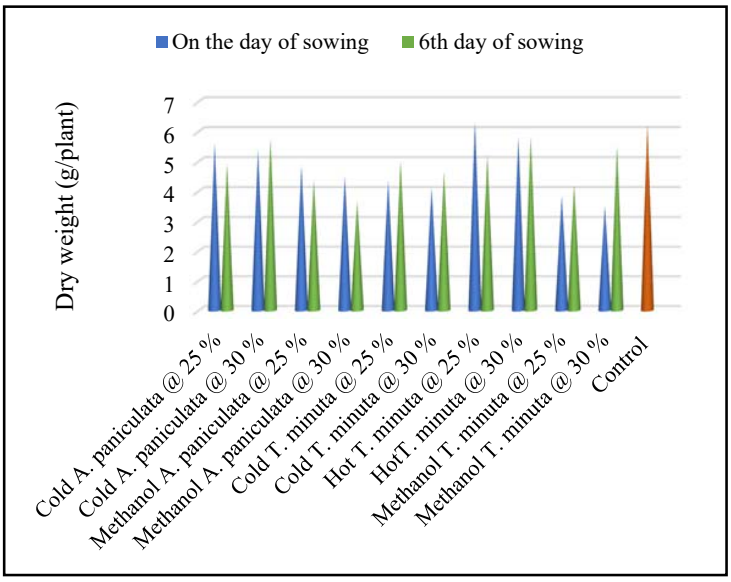


Fig. 26 Interaction between time of application and allelopathic extracts on dry weight at one month after application

B) Observations on weeds

Weed count at 3, 6, 12 and 25 DAS

Major weeds observed in the experiment were *Panicum repens*, *Boerhavia diffusa*, *Alternanthera philoxeroides*, *Emilia sonchifolia*, *Cleome viscosa*, and *Euphobia hirta*. Allelopathic effect of selected plants showed significant phytotoxic effect on these weeds.

Germination count of weeds in pot culture studies with cowpea, green gram and rice showed significant difference at 3rd and 6th days after sowing based on the time of application of the extracts (Tables 30a, 30b and 30c, Fig. 27). Allelopathic potential of extracts to control or inhibit weed germination was more pronounced when applied pre-emergence and effect lasted for 6 DAS. Allelopathic effect was more pronounced for broad leaved weeds than grassy weeds. Sadia *et al*. (2015) reported higher inhibitory effect of *Tagetes minuta* on sun spurge (*Euphorbia helioscopia*), a broad leaf weed than on Johnson grass (*Sorghum halepense*).

Effect of extracts on germination of weeds persisted only up to 6 DAS (Fig. 28), indicating lack of residual action for the selected plant extracts. Data on germination count of weeds at 12 and 25 DAS was non significant. Many scientists (Bhadoria, 2011; Ihsan *et al*., 2015) recommended the use of allelochemicals for the production of environmentally friendly herbicides since they bestowed few environmental problems in the soil due to the fairly high degradability.

In pots with cowpea, no weeds were germinated at 3 DAS when treatments were applied on the day of sowing, as compared to 21.52 nos./m^2 in control treatment. At 6 DAS, lower weed count of 27.78 nos./m^2 was observed with 30 and 25 per cent methanol extracts of *Tagetes minuta*. As compared to control, all the treatments with allelopathic extracts applied on the same day of sowing recorded significantly lower weed count. In green gram at 3 DAS, maximum inhibition in weed germination was observed when treatments were applied on the day of sowing (1.68 nos./m^2) over the application at 6th day of sowing (13.47 nos./m^2), indicating pre emergence action of

selected extracts. At 6 DAS also, the lowest weed count of 68.18 nos./m^2 was observed when treatments were applied on the day of sowing.

Superiority of pre emergence application of extracts over their post emergence application was evident in rice also. At 3 DAS, the lowest weed count of 2.52 nos./m^2 was observed with treatments applied on the day of sowing as compared to the application at 6^{th} day of sowing. Khan *et al*. (2016) evaluated pre and post emergence activity of selected plant extracts for the control of weeds in wheat and demonstrated superiority of pre emergence application of all the plant water extracts in controlling weeds than their post emergence application.

Among different plant extracts studied, maximum reduction in germination count of weeds were noticed with 30 and 25 per cent methanol extracts of *Tagetes minuta*. However, as compared to control, all the treatments with allelopathic extracts applied on the day of sowing recorded significantly lower weed count (Table 37a, 37b, 37c). Batish *et al.* (2007) reported the allelopathic potential of *Tagetes minuta* as natural herbicide for managing rice weeds without any phytotoxicity to rice ecosystem.

Weed dry weight at 25 DAS

The results (Table 33, Fig. 29, 30, 31) clearly indicated the allelopathic effect of extracts and time of application on reducing weed dry weight in cowpea, green gram and rice. Application of allelopathic extracts on the day of sowing significantly reduced the weed dry weight as compared to control. Methanol extract of *Tagetes minuta* at 30 and 25 per cent applied on 6^{th} day of sowing also effectively reduced weed dry weights in cowpea and green gram. Lower weed dry weights of 31.13 g/m^2, 22.45 g/m^2 and 41.69 g/m^2 respectively in cowpea, green gram and rice were observed with *Tagetes minuta* 30 per cent methanol extract applied on the day of sowing. Bhadoria (2011) recommended use of *Tagetes minuta* extracts as suitable substitute for synthetic herbicides because allelochemicals did not have residual or toxic effects.

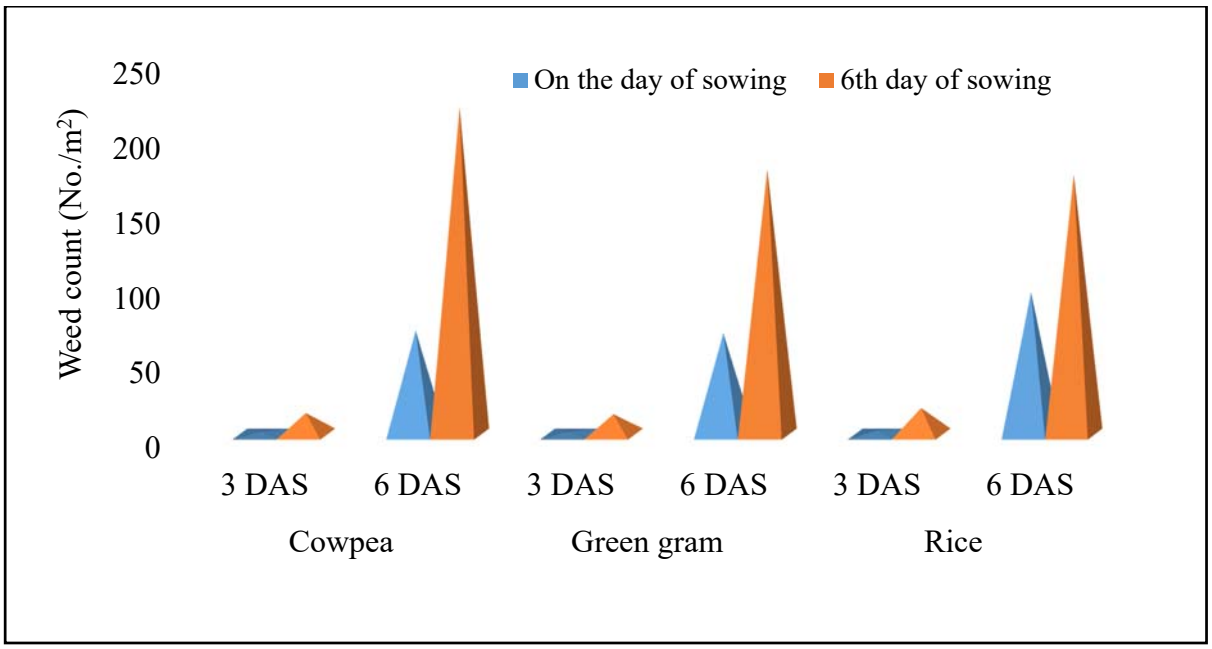
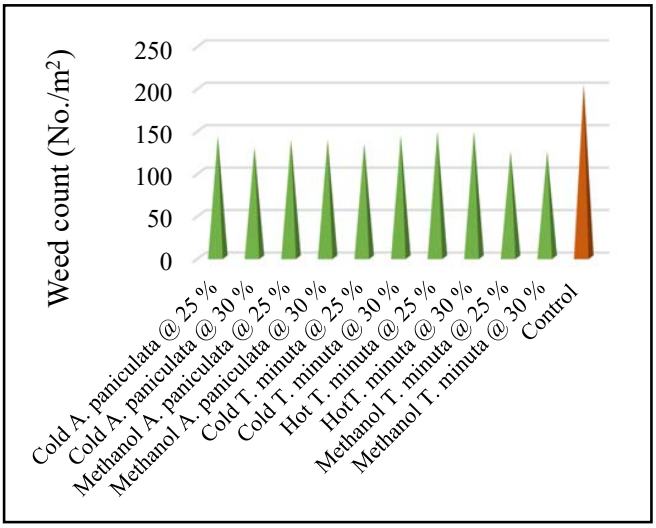
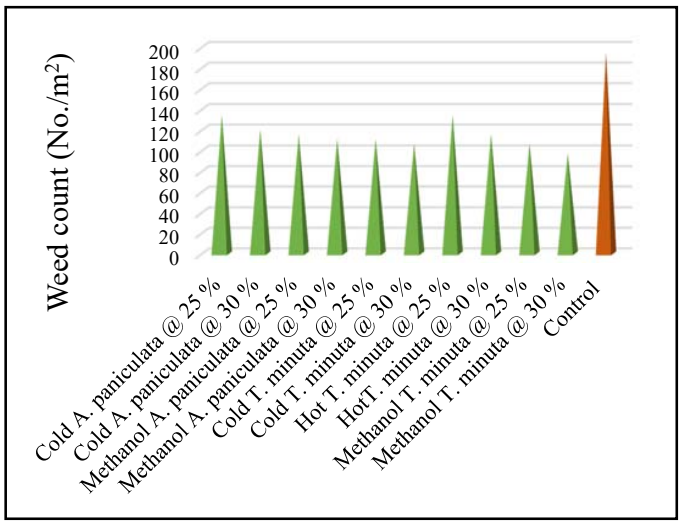


Fig. 27 Effect of time of application on weed count in cowpea and green gram and rice pot culture at 3 and 6 DAS

Cowpea



Green gram



Rice

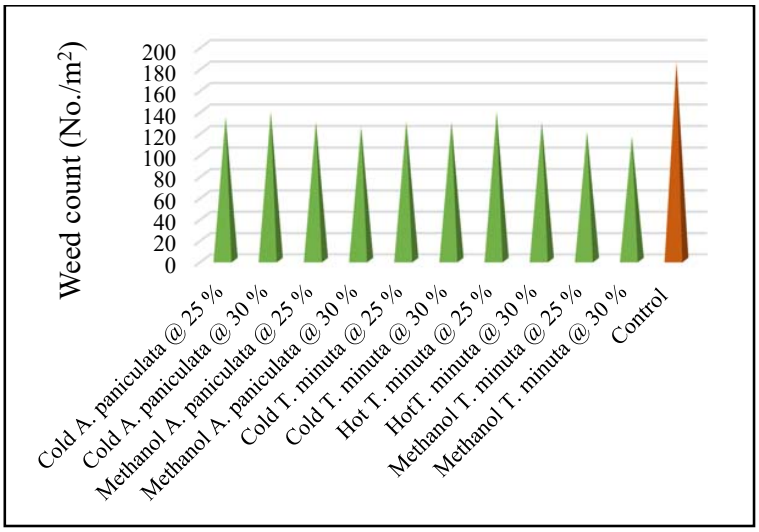


Fig. 28 Effect of allelopathic extracts on weed count at 6 DAS

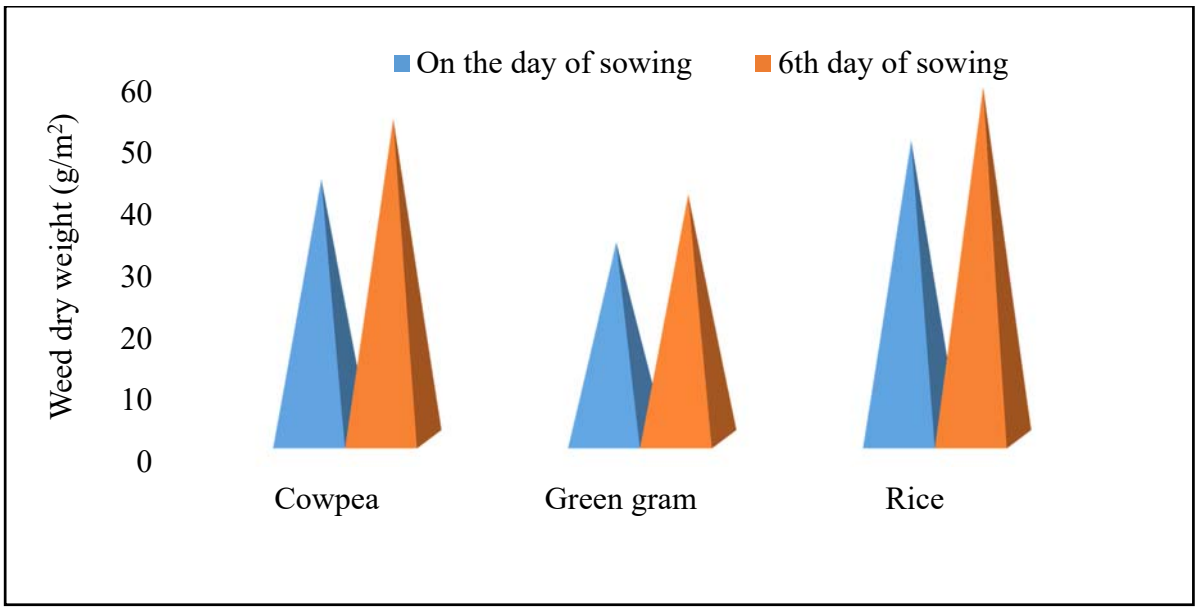
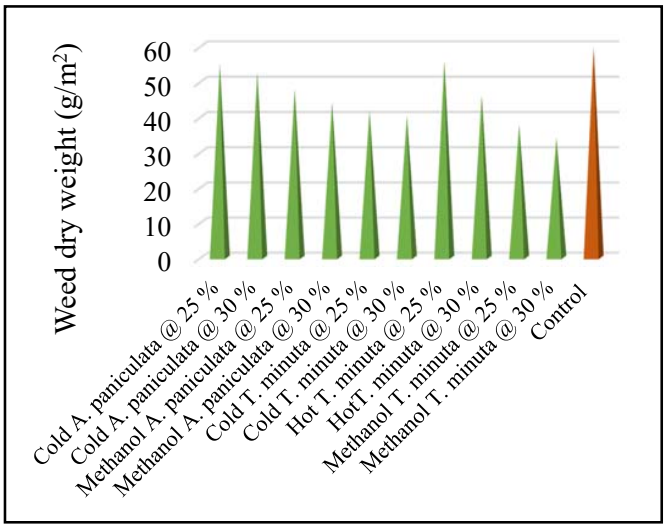
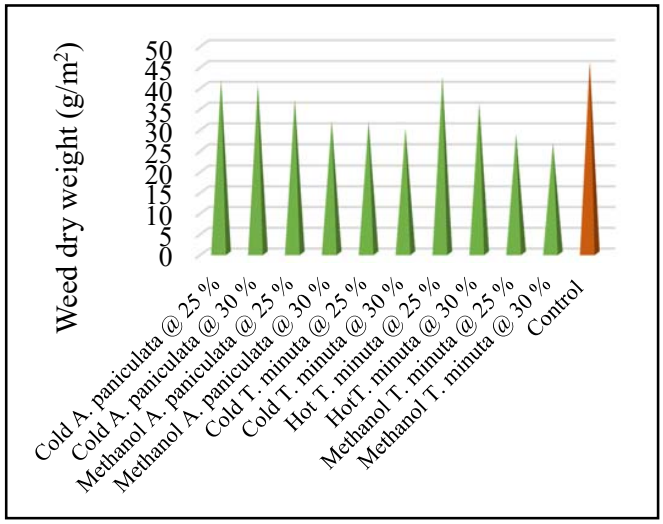


Fig. 29 Effect of time of application on weed dry weight in cowpea, green gram and rice pot culture at 25 DAS

Cowpea



Green gram



Rice

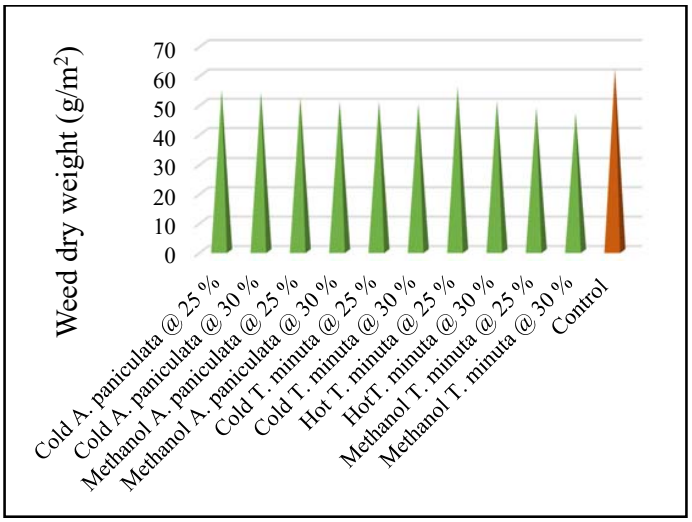
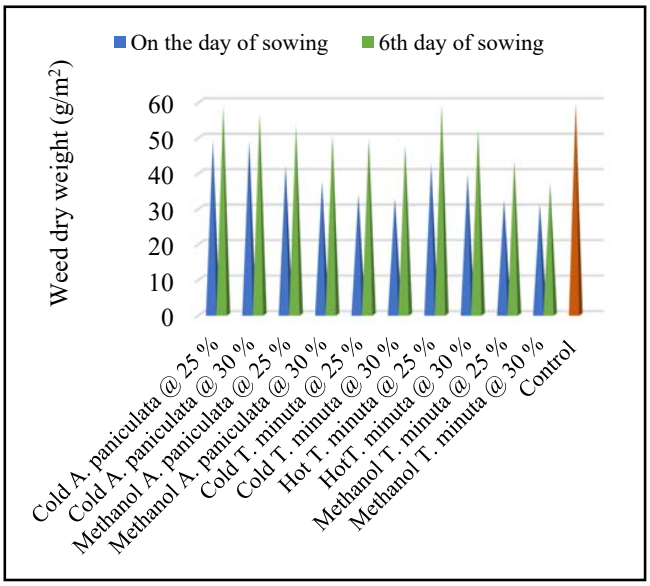
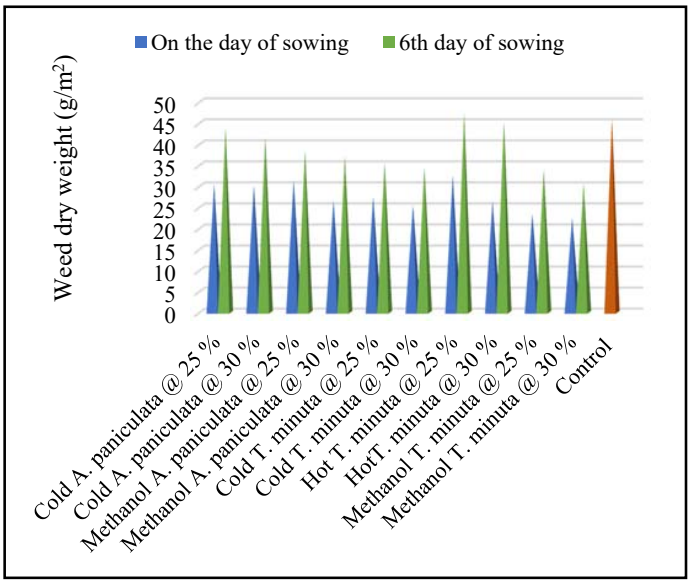


Fig. 30 Effect of allelopathic extracts on weed dry weight at 25 DAS

Cowpea



Green gram



Rice

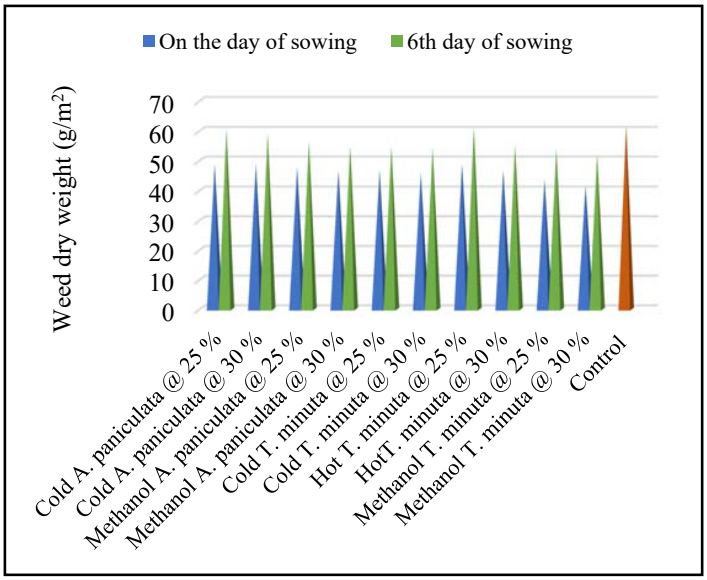


Fig. 31 Interaction between time of application and allelopathic extracts on weed dry weight at 25 DAS

Summary

6. SUMMARY

The research work entitled "Allelopathy for weed management in field crops" was conducted during February-October 2021 in the Department of Agronomy, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur. The study consisted of two parts viz., screening *Andrographis paniculata*, *Plectranthus ambonicus* and *Tagetes minuta* for their allelopathic potential and evaluating alleloapathic effect of these plant extracts on weeds and test crops rice, cowpea and green gram.The salient findings of the research are summarized and listed hereunder.

Experiment 1: Screening of selected plants for allelopathic potential against weeds

Effects of allelopathic plants

- The three allelopathic plants *Andrographis paniculata*, *Plectranthus ambonicus* and *Tagetes minuta* were rich in allelochemicals and exhibited phytotoxic activity against weeds.

- Among the plants screened for their allelopathic potential *Tagetes minuta* exhibited maximum allelopathic potential in delaying germination of weeds, followed by *Andrographis paniculata* and the lowest was by *Plectranthus ambonicus.*

- Broad leaved weeds were more sensitive to allelopathic extracts than grass weeds.

- A notable reduction in weed density and dry weight were observed by the application of allelopathic plant extracts.

Effects of method of extraction

- Method of extraction showed significant influence on allelopathic potential.

- Among methods of extraction, maximum efficiency was noticed when extracted with methanol followed by cold water extract, and least was by hot water extract.

- Higher amount of secondary metabolites were observed in methanol extracts which had higher inhibition on weed germination and reduced weed fresh and dry weights to a greater extent than other two methods.

Effects of concentration

- Weed density, delay in germination and dry weight were significantly influenced by concentrations of allelopathic extracts.
- The best results were obtained when allelopathic extracts were applied at higher concentrations of 30 and 25 per cent.
- Minimum weed inhibition was noticed from lower concentrations of 5, 10 and 15 per cent.

Effect of interaction between allelopathic plants, method of extraction and concentration

- Allelopathic effect of plants was significant only for a short period of time *i.e.* up to one week after the application.
- During first week, interaction between allelopathic plants, method of extraction and concentration had significant influence on weed density, fresh and dry weight of weeds.
- Maximum inhibition on weed growth was observed with 30 per cent methanol extract of *Tagetes minuta* followed by its 25 per cent extract.
- All extracts and concentrations of *Plectranthus ambonicus* showed lowest allelopathic effect on weeds.

Experiment 2A and 2B: Lab study and pot culture study of allelopathic effect of plant extracts on weeds and test crops

Effect of time of application

A) Effect on test crop (cowpea, green gram and rice)

- Plant extracts displayed phytotoxicity to selected test crops cowpea, green gram and rice.
- Pre emergence application of allelopathic plant extracts had more influence on crops than post emergent application.
- A notable delay in germination of test crops was observed due to application of plant extracts.
- Cowpea and green were more sensitive to allelopathic extracts than rice.

B) Effect on weeds

- Pre emergence application of allelopathic extracts had significant inhibitory influence on weeds than on test crops.
- Pre emergence application inhibited the broad leaved weeds more than the grassy weeds.
- Pre emergence application was effective up to one week after application and there after no significant influence was observed, indicating lack of residual action.

Effect of allelopathic extracts

A) Effect on test crop (cowpea, green gram and rice)

- Germination indices and seedling growth parameters of cowpea, green gram and rice were adversely affected by the application of allelopathic plant extracts.

- Shoot and root length, and fresh and dry weight were reduced by the application of allelopathic extracts.

- Root decay and reduction in number of rootlets were observed by the pre emergence application of 30 and 25 per cent methanol extract of *Tagetes minuta*.

- The inhibition was more pronounced when applied with 30 and 25 per cent of methanol extract of *Tagetes minuta*.

B) Effect on weeds

- Weed dry weight was decreased by the application of allelopathic extracts.

- Among allelopathic extracts, notable delay in weed germination was observed with 30 and 25 per cent *Tagetes minuta* methanol extract.

- Allelopathic potential of extracts and their residual effects remained in the soil up to one week.

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ALLELOPATHY FOR WEED MANAGEMENT IN FIELD CROPS

By

SHAKKIRA K. K.

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ABSTRACT OF THE THESIS

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ABSTRACT

Weeds have been a persistent menace for farmers since the advent of agriculture. Among several methods adopted for controlling weeds, chemical control is the widely used and most effective. However, the extensive use of herbicides has led to the generation of a wide range of problems including development of herbicide resistant weeds. As a result, extensive research is being done to exploit non chemical methods of weed management. The mechanism of allelopathy has been suggested as a potential biorational method towards this goal. Hence the present study entitled "Allelopathy for weed management in field crops" was conducted during February-October 2021 in the Department of Agronomy, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur.

The study consisted of two parts viz., screening *Andrographis paniculata*, *Plectranthus ambonicus* and *Tagetes minuta* for their allelopathic potential, and evaluating alleloapathic effect of these plant extracts on weeds and the test crops rice, cowpea and green gram. Cold water, hot water and methanol extracts of these plants were prepared at six concentrations viz., 5 %, 10 %, 15 %, 20 %, 25 % and 30 % in a completely randomized design (CRD) in factorial arrangement with three replications.

In the first experiment plants were screened for their allelopathic potential against upland weeds in 165 plastic trays (25 cm x 20 cm x 5 cm) that were filled to three-quarters with uniform quantity of soil (1.5 kg) collected from an open area. Best 10 treatment combinations from this experiment and a control with distilled water were carried over to the second experiment. The second experiment consisted of two parts; in petri plates to test the phytotoxic activity on test crops (cowpea, green gram and rice) and in pot culture study with test crops and weeds. Both studies were carried out in completely randomized design (CRD) in factorial arrangement with two factors and three replications. Factor A consisted of time of application (on the day of sowing and 6^{th} day after sowing). Factor B consisted of the best 10 allelopathic treatments from experiment 1.

Experiment on screening allelopathic plants for their potential to control upland weeds revealed the significant influence of the plants, the method of extraction and the concentration of extract on weed growth parameters such as weed density and weed dry weight. Broad leaved weeds were more sensitive to allelopathic extracts than grass weeds. Reduction in weed germination count and dry weight after one month of application was noticed with methanol extract of *Tagetes minuta* at 30 per cent concentration and was 6.67 nos./m^2 and 21. 33 g/m^2 respectively as compared to control (68.33 nos./$m^2$and 54. 25 g/m^2). Pre mergence application of *Andrographis paniculata* methanol extract at 30 per cent concentration was the next best treatment. Allelopathic effect of plants was significant only for a short period of time *i.e.* up to one week after application, indicating absence of residual action.

Germination indices and seedling growth parameters of test crops were adversely affected by the application of allelopathic extracts. Among test crops, cowpea and green gram were more sensitive to allelopathic extracts than rice. A notable delay in germination of test crops, in shoot and root length, and in fresh and dry weights were observed by the application of allelopathic treatments. Phytotoxicity symptoms were observed on test crops both under laboratory condition and in pot culture. Root decay and reduction in number of rootlets were observed by the pre emergence application of 30 and 25 per cent methanol extract of *Tagetes minuta*. When *Tagetes minuta* methanol extract was applied at 30 or 25 per cent as pre mergence treatment, germination of cowpea and green gram started on the 4^{th} and 5^{th} day after sowing as compared to the 2^{nd} day in control. Root length reduction was more pronounced than shoot length reduction. The reduction was 43.29 and 41.46 per cent in cowpea, and 41.56 and 37.05 per cent in green gram, due to pre emergence application of 30 and 25 per cent methanol extract of *Tagetes minuta* in petri plates. In pot culture study, root reduction of 70.85 and 71.01 per cent in cowpea and green gram by the pre emergence application of 30 per cent methanol extract of *Tagetes minuta* as was observed. A notable delay in weed germination and weed dry weight reduction were observed by 30 and 25 per cent *Tagetes minuta* methanol extract applied as pre emergence treatment and their residual inhibitory effect in the soil persisted up to one week.

Based on the results of the study, pre emergence application (on the day of sowing) of methanol and cold water extracts of *Tagetes minuta* and *Andrographis paniculata* at 30 per cent concentration can be recommended for control of broad leaved weeds in uplands.